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NOTE ON BRINELL AND SCRATCH TESTS FOR HARDENED STEEL.

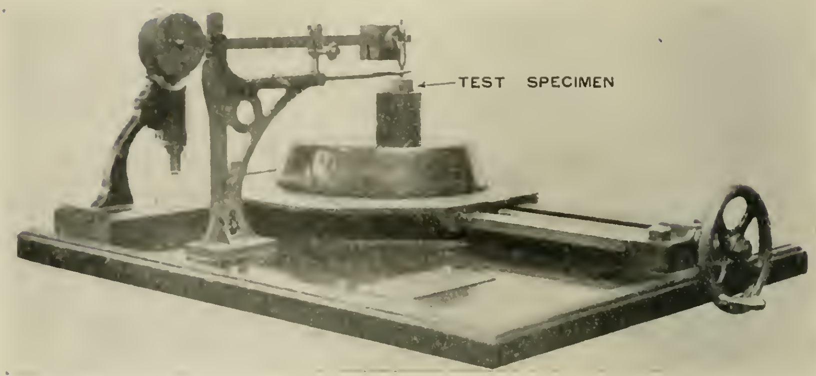
By Sir ROBERT A. HADFIELD, Bart., F.R.S., *Vice-President*, And S. A. MAIN, B.Sc., of Sheffield.

[*Selected for Publication only.*]

It is well-known that the Brinell method of testing hardness is unsatisfactory, if applied to very hard substances, such as hardened steel. One source of error is that due to the deformation of the ball. A series of experiments was therefore undertaken with the object of ascertaining how far a modified form of scratch test is applicable to hardened steel. In view of Professor Thomas Turner's established reputation in connexion with scratch testing, the results were submitted to him, and in his opinion are worthy of publication. The Authors are much indebted to him for help in the drafting of this Note, and also for useful suggestions regarding further work.

The instrument employed, which is a modification of Professor Turner's sclerometer, is shown in Fig. 1 (page 582). It was manufactured by Messrs. W. and T. Avery, of Birmingham, from a design prepared by Mr. W. E. Alkins, B.Sc., in consultation with Professor Turner. The experiments were conducted in the Research Department of Hadfields Ltd., of Sheffield. The apparatus was

Fig. 1.—*Scratch Testing Apparatus.*



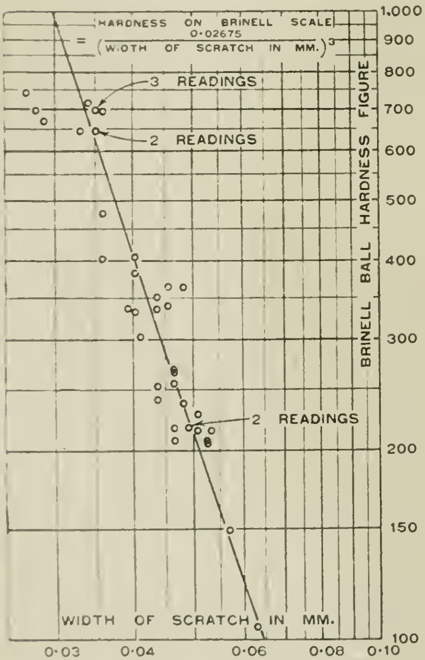
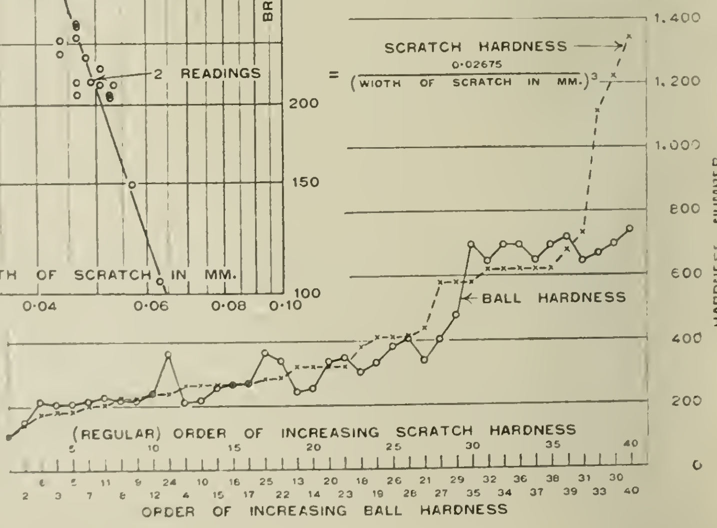


Fig. 2.—*Brinell Hardness and Width of Scratch with Uniform Load.*

Fig. 3.—*Comparison of Scratch and Ball Hardness on forty Steel Specimens of varying Hardness.*



originally designed for testing the hardness of steel helmets, and would need some modification in order to be suitable for research work, or other purposes.

It will be seen that the apparatus is of a simple character, consisting of a balanced-lever arm, fitted with jockey-weight, and carrying at its end a diamond point. The diamond is drawn along the surface of the metal to be tested, thus making a scratch. In each case the surface of the piece was polished before testing. The test-piece was placed under the weighted diamond point, and was held firmly by hand. A turn was then given to the small wheel, which is connected with a threaded screw, and moves the table and test-piece. A constant weight of about 6 oz. was employed, and the width of the scratch was measured by means of a special measuring microscope, supplied by Watson, which is part of the equipment. The scale on the eye-piece was arbitrary, and was not calibrated to represent inches or millimetres. It was, therefore, calibrated by means of an engine-divided scale, when it was found that one division on the microscope was equal to 0·0175 mm.

A series of test-pieces were prepared, and these varied in hardness from soft to glass-scratching hardness, so as to give a considerable range. After the scratch test had been completed, a Brinell hardness test was performed on each piece, close to the scratch, so as to obtain a definite comparison by the two methods. The results of the experiments are given in the Table (page 585), and are graphically represented in Figs. 2 and 3. The diamond points used in such tests are usually pyramidal in shape, having four flat sides, and it is advisable that the diamond shall always be so placed that two edges shall be in the line of scratch. Unfortunately, in the present experiments the orientation of the diamond was not noted, though it remained the same throughout the whole series.

From an examination of the results, it would appear that the scratch hardness obtained by the method above described, bears a general relation to the Brinell hardness, which can be represented approximately by the formula

$$\text{Brinell Hardness} = \frac{0{\cdot}02675}{(\text{width of the scratch in mm.})^3}$$

This would appear to show that the two methods measure somewhat similar properties in the metal to be tested, and it may be possible to establish a scratch test giving hardness figures corresponding generally with the Brinell scale but not subject to the disabilities of the Brinell. It may be observed, however, that as the two methods must to some extent register different properties, it cannot be expected that uniform results will be obtained. In examining Fig. 3 it will be observed that the scratch hardness figures, when taken in accordance with the above formula, have been plotted against the Brinell figures, and though the general agreement is satisfactory, having regard to experimental errors, there are some important exceptions.

The tests of particular interest are the last four on the diagram. In these there is a wide divergence between ball and scratch hardness tests, the scratch figures being 730, 1,110, 1,220, and 1,345 respectively, as against ball-hardness figures of 645, 670, 696, and 741. The hardness of these specimens, which are all in the very high range, is therefore considerably greater when measured by the scratch test than by the ball test, which confirms the breaking down of the Brinell method with increase in hardness.

Though only moderate accuracy can be claimed for the scratch tests in the present experiments, it can be said with confidence that the error in testing is not sufficient to account for the difference found. This may indicate that the scratch test does, in some cases, deal with a different aspect of hardness from that indicated by the Brinell test. For reasons above mentioned, it has not been possible to confirm the above figures by repeating experiments under exactly similar conditions, but the results obtained do appear to show that the ball-hardness method is unsatisfactory when dealing with very hard material. The hardness of very hard steel as measured by the scratch test is much higher than is indicated by the ball-hardness method.

On the other hand the lack of sensitiveness of the scratch method, which is a difficulty in its use, is rendered very apparent by the relationship found above. A slight difference in the width of the scratch on two specimens corresponds with a difference in

Comparison of scratch and Brinell hardness of steel with uniform load.

Arranged in order of increasing scratch hardness.

Scratch Test.			Brinell Ball Hardness Figure.
Width of Scratch.		Scratch Hardness Figure taken as $\frac{0\cdot02675}{(\text{width of scratch in mm.})^3}$.	
Divisions on Watson Microscope scale. 1 div. = 0·0175 mm.	Mm.		
3·6	0·0630	107	104
3·25	0·0569	145	149
3·05	0·0534	175	214
3·0	0·0525	185	205
3·0	0·0525	185	207
2·9	0·0507	205	215
2·9	0·0507	205	228
2·8	0·0490	227	217
2·8	0·0490	227	217
2·75	0·0481	239	238
2·75	0·0481	239	364
2·7	0·0465	265	207
2·7	0·0465	265	217
2·7	0·0465	265	255
2·7	0·0465	265	267
2·7	0·0465	265	269
2·6	0·0455	284	364
2·45	0·0454	286	340
2·5	0·0437	321	241
2·5	0·0437	321	353
2·5	0·0437	321	337
2·5	0·0437	321	351
2·35	0·0411	379	302
2·3	0·0402	412	332
2·3	0·0402	412	382
2·3	0·0402	412	405
2·25	0·0394	437	337
2·05	0·0359	578	402
2·05	0·0359	578	477
2·05	0·0359	578	690
2·0	0·0350	622	645
2·0	0·0350	622	696
2·0	0·0350	622	696
2·0	0·0350	622	645
2·0	0·0350	622	696
1·95	0·0341	675	718
1·9	0·0332	730	645
1·65	0·0289	1,110	670
1·6	0·0280	1,220	696
1·55	0·0271	1,345	741

hardness proportional to the cube; or, expressed in another way, the probable error in the hardness figure is approximately three times the probable error in measuring the scratch. This difficulty, however, unlike that in the Brinell test, is amenable to refinement of method and skill in manipulation.

The series of experiments above described are not presented as being in any sense complete or conclusive, but rather as one step in the endeavour to ascertain the best method of hardness testing for very hard materials, and the relationship which may exist between the results obtained when employing different methods of testing.

The formula derived should be regarded as a quite tentative and empirical relationship between Brinell and scratch hardness of steel. The establishment of a satisfactory and rational hardness scale for the scratch method will involve further work, including the determination of the relation between pressure and width of scratch.

The Authors have pleasure in acknowledging the assistance of Mr. A. Stevenson in carrying out the experiments.

The Paper is illustrated by 3 Figs. in the letterpress.

ON FRICTION BRAKES WITH STRAPS STIFFENED BY WOOD BLOCKS.

By WALTER PITT, of Bath, *Member*.

[Selected for Publication only.]

The ordinary formula for brake-bands embracing an arc α is $\frac{T}{t} = e^{\mu\alpha}$ where T and t are the tensions in the strap ends and $\mu = \tan\phi$ = coefficient of friction. When the strap has wooden blocks rigidly attached to it, the above formula requires some modification, Fig. 1 (page 588).

If we consider the conditions of equilibrium of a single block, Fig. 2, we find three forces acting, namely, two tensions t_1 and t_2, and a resultant R of the forces on the underside of the block. For small spaces between the blocks such as obtain in practice, the directions of the forces t_1 and t_2 may be taken as tangents at the points A and B. For blocks of moderate length it may be assumed that at the moment when slipping commences the resultant R makes an angle ϕ with the radius at C; for equilibrium, R must pass through D.

Let n be the number of blocks in the arc α, then angle AOD = angle BOD = $\frac{\alpha}{2n}$.

Let AE and BF be the perpendiculars from A and B on the directions of t_1 and t_2; and AG and BH similar perpendiculars on R. By symmetry AD = BD and AE = BF.

Let angle CDO = β, and angle ADO = angle BDO = $\frac{\pi}{2} - \frac{\alpha}{2n}$.

Taking moments round B we have for equilibrium—

$$t_1 \times \mathrm{BF} = \mathrm{R} \times \mathrm{BH} = \mathrm{R} \times \mathrm{BD} \sin\left(\frac{\pi}{2} - \frac{\alpha}{2n} + \beta\right) = \mathrm{R} \times \mathrm{BD} \cos\left(\frac{\alpha}{2n} - \beta\right)$$

Similarly by moments round A—

$$t_2 \times \mathrm{AE} = \mathrm{R} \times \mathrm{AG} = \mathrm{R} \times \mathrm{AD} \sin\left(\frac{\pi}{2} - \frac{\alpha}{2n} - \beta\right) = \mathrm{R} \times \mathrm{BD} \cos\left(\frac{\alpha}{2n} + \beta\right)$$

whence
$$\frac{t_1}{t_2} = \frac{\cos\left(\frac{\alpha}{2n} - \beta\right)}{\cos\left(\frac{\alpha}{2n} + \beta\right)} = \frac{1 + \tan\frac{\alpha}{2n}\tan\beta}{1 - \tan\frac{\alpha}{2n}\tan\beta}.$$

FIG. 1.

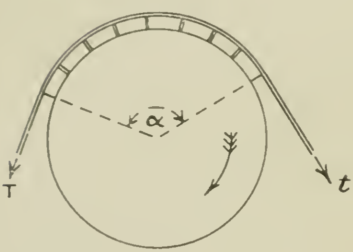
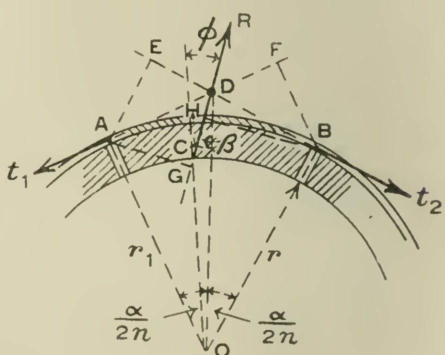


FIG. 2.



For the whole arc α and n effective blocks—

$$\frac{\mathrm{T}}{t} = \left\{\frac{1 + \tan\frac{\alpha}{2n}\tan\beta}{1 - \tan\frac{\alpha}{2n}\tan\beta}\right\}^n \quad . \quad . \quad . \quad (1)$$

For calculating β we have from the triangle COD—

$$\frac{\sin\beta}{\sin\phi} = \frac{r}{\mathrm{OD}}$$

but from the triangle AOD—

$$\frac{\mathrm{AO}}{\mathrm{OD}} = \cos\frac{\alpha}{2n}, \quad \text{whence } \sin\beta = \frac{r}{\mathrm{AO}}\cos\frac{\alpha}{2n}.\sin\phi \qquad (2)$$

putting AO $= r_1 =$ mean radius of strap—

$$\sin \beta = \frac{r}{r_1} \cos \frac{a}{2n} \sin \phi \quad . \quad . \quad . \quad . \quad (2)$$

All the quantities a, n, r, r_1, are procurable from the drawing of the brake.

If the above be correct, then, for an infinite number of infinitely thin blocks, the expression for $\frac{T}{t}$ should become $e^{\mu a}$, where $\mu = \tan \phi$ = coefficient of friction. This can be shown as follows—

At the limit, $\tan \frac{a}{2n} = \frac{a}{2n}$, $r = r_1$, $\sin \beta = \sin \phi$, $\beta = \phi$,

whence
$$\frac{T}{t} = \left\{\frac{1 + \tan \frac{a}{2n} \tan \beta}{1 - \tan \frac{a}{2n} \tan \beta}\right\}^n = \left\{\frac{1 + \mu \frac{a}{2n}}{1 - \mu \frac{a}{2n}}\right\}^n.$$

By a well-known expansion—

$$\log_e \left(\frac{1 + x}{1 - x}\right) = 2 \left\{x + \frac{x^3}{3} + \frac{x^5}{5} + \cdot \cdot \cdot \cdot\right.$$

therefore—

$$\log_e \frac{T}{t} = n \times 2 \left\{\mu \frac{a}{2n} + \mu^3 \left(\frac{a}{2n}\right)^3 + \cdot \cdot \cdot \cdot\right.$$

Discarding the higher powers at the limit, we get—

$$\log_e \frac{T}{t} = \mu a$$

or
$$\frac{T}{t} = e^{\mu a}$$

There remains to be considered the stiffness of the strap.

To bend a prismatic bar to a radius of curvature r requires a bending moment $M = \frac{EI}{r}$ where E is the modulus of elasticity, and I the moment of inertia of the section.

The work done in bending through the arc a is $Ma = \frac{EI}{r} a$.

Let r_2 be the mean radius of the strap just before clinging commences, and r_1 the mean radius of the tight strap as before, then the work done in pulling the strap tight is—

$$\frac{EI}{r_1} a - \frac{EI}{r_2} a = EI \frac{r_2 - r_1}{r_1 r_2} a.$$

As r_1 and r_2 differ only very slightly, we may neglect any variation of the arc a, and then the "take up" of the strap will be $r_2 a - r_1 a$. If we call P_s the pull required to pull the strap tight, we get by equating the work—

$$P_s (r_2 - r_1) a = EI \frac{r_2 - r_1}{r_1 r_2} a$$

or

$$P_s = \frac{EI}{r_1 r_2}$$

but as we have assumed r_1 and r_2 to be nearly equal, we may write—

$$P_s = \frac{EI}{r_1^2} \quad . \quad . \quad . \quad . \quad (3)$$

If F is the required force at the circumference of the brake drum—

$$F = (T - t) \text{ or } t = \frac{F}{\frac{T}{t} - 1} \quad . \quad . \quad . \quad (4)$$

and the total pull required is—

$$P = t + P_s \quad . \quad . \quad . \quad . \quad (5)$$

The following numerical calculations are taken from actual practice :—

CASE I.—Load on brake rim 1·667 tons = 3733 lb.

$a = 270°$.

Number of blocks = 11. Thickness of blocks $1\frac{1}{4}''$.

Diameter of drum = 3′. $r = 18''$.

Mean radius of strap 19·34″.

Strap $4\frac{1}{2}'' \times \frac{3}{16}''$.

$\mu = \frac{1}{5}$, $\tan \phi = \cdot 2$, $\phi = 11° 19'$, $\sin \phi = \cdot 196$.

$$\sin \beta = \frac{r}{r_1} \cos \frac{a}{2n} . \sin \phi = \frac{18}{19 \cdot 34} \cos 12° 16' \times \cdot 196 ;$$

whence $\beta = 10° 16'$, $\tan \beta = \cdot 1811$.

$$\frac{T}{t} = \left\{\frac{1 + \tan 12° 16' \tan 10° 16'}{1 - \tan 12° 16' \tan 10° 16'}\right\}^{11}$$

$$= \left\{\frac{1 + \cdot 2174 \times \cdot 1811}{1 - \cdot 2174 \times \cdot 1811}\right\}^{11} = \left\{\frac{1 \cdot 0394}{\cdot 9606}\right\}^{11}$$

$$\frac{T}{t} = 2 \cdot 38$$

$$t = \frac{F}{\frac{T}{t} - 1} = \frac{3733}{1\cdot38} = 2705 \text{ lb.}$$

For a strap $4\frac{1}{2}'' \times \frac{3}{16}''$, $I = \cdot002465$ inch^4, $E = 27{,}000{,}000$

$$P_s = \frac{EI}{r^2} = \frac{27{,}000{,}000 \times \cdot002465}{19\cdot34 \times 19\cdot34} = 178 \text{ lb.}$$

and the total pull required is—

$$P = 2705 + 178 = 2883 \text{ lb.}$$

The ordinary formula gives—

$$\frac{T}{t} = e^{\frac{1}{5} \cdot \frac{3\pi}{2}} = 2\cdot56$$

and $P = 2390$, or an error of about 17 per cent.

Case II.—Load on brake rim = 2690 lb.
Diameter of brake drum = 30″.
Arc embraced 270°.
Number of blocks 12. Thickness of blocks $1\frac{1}{4}''$.
Strap $3\frac{1}{2}'' \times \frac{3}{16}''$.
Coefficient of friction = $\frac{1}{5}$.

From the above we find—

$r = 15''$, $r_1 = 16\cdot34''$, $\tan\phi = \cdot2$, $\frac{a}{2n} = 11°\ 15'$, $I = \cdot001915$,

and from equation (2) we find $\beta = 10°\ 10'$,

whence
$$\frac{T}{t} = \left\{\frac{1 + \tan 11°\ 15' \tan 10°\ 10'}{1 - \tan 11°\ 15' \tan 10°\ 10'}\right\}^{12}$$

$$\frac{T}{t} = 2\cdot37$$

$$t = \frac{2690}{1\cdot37} = 1963 \text{ lb.}$$

$$P_s = \frac{EI}{r_1^2} = \frac{27{,}000{,}000 \times \cdot001915}{16\cdot34 \times 16\cdot34} = 194 \text{ lb.}$$

and the total pull required is

$$P = 1963 + 194 = 2157 \text{ lb.}$$

In this case the $e^{\mu a}$ formula gives

$$P = 1725 \text{ lb.}$$

or an error of 20 per cent.

The Paper is illustrated by 2 Figs. in the letterpress.

THE MEASUREMENT OF AIR FLOW BY VENTURI METER.

By Professor A. H. GIBSON, D.Sc., of University College, Dundee, *Member*.

[*Selected for Publication only.*]

(1) In any installation designed for the bench testing of carburettors, it is necessary to have some means of measuring the rate of air flow through the carburettor, and as, in order to reproduce operating conditions, free influx of air to the carburettor intake must be permitted, the measuring device requires to be fitted in the pipe-line between the carburettor and the exhauster.

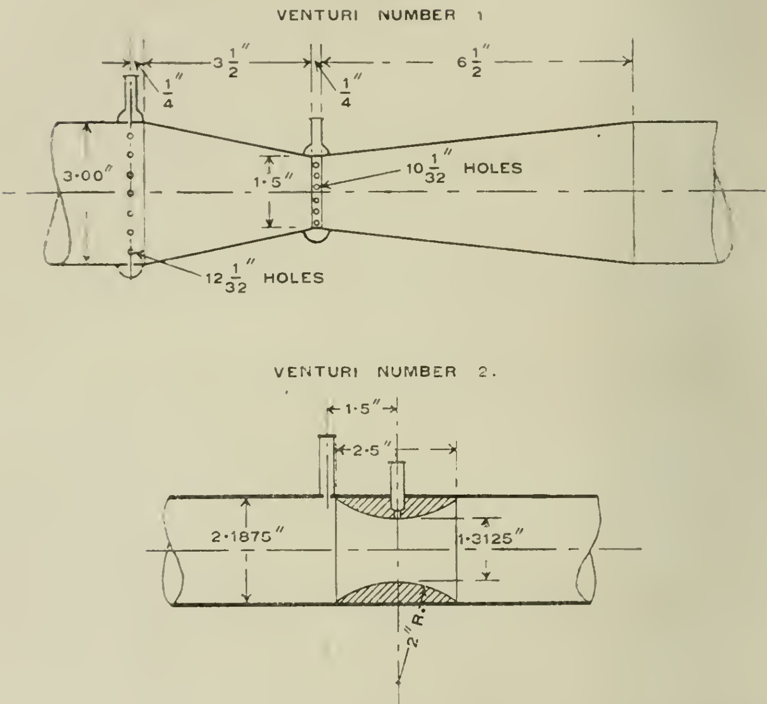
On account of its simplicity and of the convenience with which it can be fitted as part of such an installation, the Venturi meter suggests itself as the most satisfactory instrument for measuring the air flow, and in an installation recently designed by the Author, it was decided to adopt this method.

As the tests of a carburettor—especially for aero-engine work—require to be carried out over a wide range of air flows corresponding to different engine-speeds, and over a range of throttle-openings giving in some cases considerable depressions in the carburettor, such a meter requires to operate under extreme conditions, and the pressure at the throat may become very low.

There appears to be little if any available data as to the value of the coefficient of discharge of a Venturi meter under such conditions,* and in order to obtain such data, a calibration of two meters was carried out.

(2) These are shown in Fig. 1. Meter No. 1 was specially

Fig. 1.



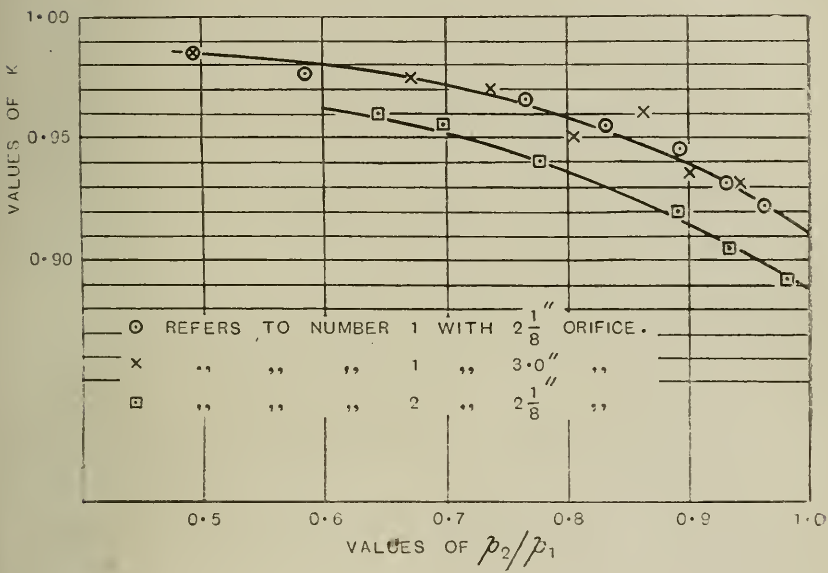
designed for this work, while No 2 was a meter crudely constructed by fitting the choke-tube from an existing aero-carburettor into a suitable parallel pipe, with the idea of determining how far

* Hodgson. Proc. Inst. C.E., Vol. CCIV. page 131, gives curves for the coefficient of discharge of a series of nozzles, one of which approximates to the cone of a Venturi Meter. Hodgson states (page 155 *ibid*) that values of the coefficient are constant for any one nozzle, a result which is contradicted by other experiments.

the air flow could be deduced in flight from measurements of the throat depression in such a carburettor.

During the calibrations, the air supply to the meter was drawn through a large air-box having a carefully formed sharp-edged orifice in the centre of one face. The pressure drop across this orifice was measured by means of a Threlfall gauge and the coefficient of discharge was taken from the values given by Prof. W. Watson.*

Fig. 2.



The whole of the conditions were chosen so as to reproduce as far as possible the conditions obtaining in these experiments. Two series of tests were made. In one the diameter of the orifice was 2·125 inches, in the other 3·00 inches. The results of the two series agree very closely as shown by the curves of Fig. 2. As a further check the meter was afterwards used in series with a calibrated anemometer. Here again the results were consistent within 1 per cent. over the whole range of air flows.

* Proc. I.Mech.E. 1912, page 517.

The results of the calibrations, using the two orifices, are given in the Table (page 597), while values of the coefficient of discharge as deduced from these calibrations are given in the Table and in the curves of Fig. 2.

(3) On the usual assumptions that expansion in the nozzle takes place according to the law pv^n = Constant; that the loss of energy between throat and entrance is negligible; that the square of the mean velocity of flow at a given section is equal to the mean of the squares of the velocities over the section, and that the measured pressures at the throat and entrance are the true mean pressures at these sections, it may be shown that :—

$$W = KA_1 \beta \sqrt{2g P_1 W_1} \text{ lb. per second} \quad . \quad (1)$$

$$\text{where } \beta = \sqrt{\frac{\frac{n}{n-1}\left\{1-\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}\right\}\left(\frac{p_2}{p_1}\right)^{\frac{2}{n}}}{m^2-\left(\frac{p_2}{p_1}\right)^{\frac{2}{n}}}}$$

Where A_1 is the sectional area at the entrance in sq. feet.

,, P_1 ,, pressure at entrance in lb. per sq. ft.

,, p_1 ,, pressure at the entrance in lb. per sq. in.

,, p_2 ,, ,, ,, throat ,, ,,

,, w_1 ,, weight per cub. ft. at p_1, and temperature T_1.

,, m is $= \frac{A_1}{A_2}$

,, K is an experimental coefficient of discharge.

If τ_1 be the absolute temperature at entrance, on the Fahrenheit Scale, on putting $W_1 = 2 \cdot 700 \frac{p_1}{\tau_1}$ (the value for dry air) equation (1) reduces to

$$W = 1 \cdot 099 \, Ka_1 \beta \frac{p_1}{\sqrt{\tau_1}} \text{ lb. per second} \quad . \quad . \quad (2)$$

where a_1 is the entrance area in sq. inches.

For dry air expanding adiabatically, $n = \gamma$. In the experiments in question the degree of saturation of the air supply was sensibly constant and equal to $0 \cdot 74$. The effect of humidity in modifying the constants has been neglected.

TABLE.

Experiment No.	Absolute pressure cmm. Mercury. p_1	p_2	$\frac{p_2}{p_1}$	Q lb. per sec.	Coefficient of discharge.	
1	61·2	30·3	·495	·485	·985	No. 1 Venturi Meter. Measuring orifice $2\frac{1}{8}$-in. diameter. Temp. = 56° F.
2	62·8	42·2	·672	·472	·975	
3	63·8	46·8	·734	·453	·970	
4	65·7	53·1	·809	·414	·950	
5	67·7	58·5	·865	·361	·960	
6	69·6	62·9	·902	·325	·935	
7	71·7	67·6	·944	·257	·932	
1	66·4	33·0	.497	·529	·986	No. 1 Venturi Meter. Measuring orifice 3·0-in. diameter. Temp. = 56° F.
2	66·9	39·4	·589	·526	·977	
3	68·4	51·5	·768	·462	·966	
4	70·1	58·4	·834	·414	·955	
5	71·8	64·3	·895	·345	·945	
6	73·2	68·5	·936	·277	·932	
7	74·05	71·4	·964	·214	·922	
1	61·74	39·9	·646	·363	·960	No. 2 Venturi Meter. Measuring orifice $2\frac{1}{8}$-in. diameter. Temp. = 69°F.
2	62·4	43·6	·700	·354	·956	
3	65·83	51·1	·777	·336	·940	
4	69·79	62·3	·893	·259	·920	
5	71·3	66·6	·935	.2125	905	
6	74·73	73·46	·983	·1159	893	

(4) On calculating the values of the coefficient of discharge by inserting measured values of W in equation (2), it was found in every case that these values are not constant, but increase as the ratio $\frac{p_2}{p_1}$ is diminished, the relative increase being approximately 8·0 per cent. in each case, as this ratio diminishes from unity to 0·6.

The values of K as determined from a smooth curve between the plotted points, Fig. 2, are as follows:—

$\frac{p_2}{p_1}$

—	0·5	0·6	0·7	0·8	0·9	1·0
Venturi No. 1 . . .	0·984	0·980	0·972	0·958	0·940	0·911
Venturi No. 2 . . .	—	0·960	0·952	0·936	0·915	0·889

(5) This same phenomenon of a relative increase in the coefficient of discharge accompanying an increased ratio of inlet to discharge pressures has been noted by other observers in connexion with the flow of air and of steam through nozzles and orifices,* though it has not hitherto definitely been shown to exist under the conditions obtaining in a Venturi Meter.

Thus Professor Rateau † in experiments on bell-mouthed orifices, and on a straight-sided convergent nozzle, obtained the following values for the coefficient of discharge for steam flow:—

$\frac{p_2}{p_1}$

—	0·6	0·7	0·8	0·9	1·0
K . .	0·996	0·974	0·967	0·954	0·92

* *See* Prof. J. B. Henderson, D.Sc., Proc. Inst. Mech. Eng. 1913, p. 253, also J. G. Stewart, Proc. Inst. Mech. Eng. 1914, p. 949.

† Rateau on "The Flow of Steam." Constable & Co., London.

The close agreement between these results and those obtained for Venturi No. 1 is worthy of note. The values in the latter case are about 1 per cent. lower than those obtained by Rateau, but the relative diminution with an increase in $\frac{p_2}{p_1}$ is practically the same, so that the phenomenon is sensibly the same with air or with steam.

Another point worthy of attention is that in spite of the great difference in the shape of the upsteam nozzle in the two Venturi meters, the relative diminution in the value of K, with an increase in $\frac{p_2}{p_1}$ is the same in each case. The same fact is to be noted in the experiments by Professor Rateau, in which the nozzles experimented upon were of widely differing shapes.

A further point to be noted in the present experiments is that the temperature of the expanding gas was below that of its surroundings, and that in consequence any transference of heat would tend to heat the gas. In contradistinction to this we have the same increase in K shown in experiments on expanding steam where the steam is at a higher temperature than, and is losing heat to, its surroundings.

(6) These facts would tend to throw some light on the various suggestions that have been offered in explanation of the phenomena. Thus it has been suggested—

(*a*) That this is due to the fact that expansion is not adiabatic, the difference being due to heat-flow through the walls, or to conduction of heat along the wall of the nozzle from the comparatively hot entrance to the comparatively cool throat.

Where, as in the case under consideration, the expanding fluid is at a lower temperature than its surroundings, it may be shown, since the heat given to be gas per second is given by—

$$\mathrm{U\ W}\frac{\gamma-n}{\gamma-1}$$

where U is the work done per lb. of the air during expansion, and since this influx of heat through the walls of the nozzle per second is sensibly proportional to $\tau_1 - \tau_2$ (the mean difference of

temperature between the inside and outside air), that while this influx of heat in itself will cause the value of n to be less than γ throughout the whole range of expansion, it will have the effect of making n relatively greater for the higher degrees of expansion, and this would give a calculated coefficient of discharge increasing with a diminution in the ratio $\frac{p_2}{p_1}$.

On the other hand, where the surroundings are cooler than the nozzle, as in steam-flow experiments, this heat flow will have the converse effect and the apparent value of n, so affected by this factor, will be relatively less for the higher degrees of expansion.

In view of the fact that the same relative increase in the coefficient of discharge is obtained whether the heat influx is inward or outward, and whether flow takes place in a small or a large nozzle where the wall effects are very dissimilar, the effect of any such heat flow on the relative values of K would appear to be very small.

(*b*) That the effect is due to the fact that the measured pressures at throat and entrance, and more especially at the throat, are not the true mean pressures across the section under consideration. Also that the true kinetic energy at the throat is not proportional to the square of the mean velocity as determined by the mean flow.

As regards these points, it would be anticipated that any such appreciable variation of pressure across the throat section as might be produced by condensation or rarefaction due to inertia forces would be appreciably affected by the shape and degree of convergence of the entrance, and the fact that no difference is to be noted in the two meters under consideration, in spite of their great difference in shape and proportions, as also in the nozzles of Professor Rateau, would tend to discredit the first of these suggestions. Moreover, the apparent value of the coefficient would, if this effect were serious, depend on whether the pressure orifices lay in a zone of rarefaction or condensation, and if this were the controlling factor, experiments would certainly be available in which the value of K instead of uniformly increasing, diminished with an increase in $\frac{p_2}{p_1}$.

As regards the true kinetic energy at the throat, while no information is available as to the distribution of velocity across a diameter in a converging nozzle, experiments by Dr. Stanton * on air flow in parallel pipes show that for a given pipe the shape of the velocity curve changes as the velocity is increased. The nature of the change is to make the velocity curve flatter as the velocity is increased, and this tends to make the true kinetic energy approximate more nearly to the kinetic energy as deduced from the mean mass flow.

It may be shown that with such velocity curves as are obtained during pipe flow at speeds above the critical velocity, the true kinetic energy is always greater than the kinetic energy as usually calculated, the difference being of the order of 5 per cent., so that any such change in the shape of the curve will tend to give an apparently higher value of K with increasing velocity. An examination of Stanton's curves, however, would indicate that this effect is only small, unless indeed, as is possible, the shape of the velocity curves for a converging nozzle vary much more with changes of velocity than is the case in a parallel pipe. This is a point which would probably well repay investigation.

(c) That whereas when a gas expands adiabatically and slowly, the energy in the gas at any stage of expansion is divided equally, according to Boltzmann's theory of the equipartition of energy, among the different degrees of freedom of a molecule, when the expansion is very rapid the energy of rotation of the molecules, which can only do work after transformation into energy of translation, is virtually locked up. If entirely locked up, the index n in the adiabatic equation would become $1 \cdot 66$ instead of $1 \cdot 408$ in the case of air, while if partially locked up the index would have a value intermediate between $1 \cdot 66$ and $1 \cdot 4$.

For a given series of experimental observations, it may readily be shown that the values of K become more nearly uniform as the value of n is increased.

Adopting the value $n = 1 \cdot 66$, and calculating values of K for Venturi Meters (1) and (2), the following results are obtained :—

* Trans. Inst. Naval Architects, 1912.

$\frac{p_1}{p_2}$

—		0·5	0·6	0·7	0·8	0·9	1·0
Venturi No. 1 .	$n=1{\cdot}408$	0·983	0·980	0·976	0·958	0·940	0·910
	$n=1{\cdot}66$	0·900	0·897	0·893	0·889	0·884	0·877
Venturi No. 2 .	$n=1{\cdot}408$	—	0·960	0·952	0·936	0·915	0·889
	$n=1{\cdot}66$	—	0·860	0·855	0·849	0·840	0·829

From these results it appears that a value of n increasing from 1·408 at the lowest velocities to approximately 1·60 at the highest velocity would give a constant coefficient of 0·91 for the larger, and 0·89 for the smaller meter.

Actually owing to the fact that the air is not initially dry, and that during expansion it receives heat from the walls, the true values of n will be less than these for all rates of expansion.

In the extreme case one may instance the case of the expansion of air between the lowest and highest strata of the atmosphere in which the effective value of n is 1·19.

A value of n ranging from 1·2 at the lowest velocities to 1·45 at the highest velocities, would give a constant coefficient of 0·98 for Venturi No. 1, and 0·96 for Venturi No. 2.

It would appear probable that there is some such change as here indicated in the effective value of n as the ratio $\frac{p_2}{p_1}$ is diminished, and also some change in the shape of the velocity curves, at throat and entrance, and that the observed increase in the coefficient K is mainly due to a combination of these two causes.

(7) From the point of view of the user of the Venturi meter for measuring such air flows, the important points would appear to be :—

(1) Such a meter has not a constant coefficient of discharge for all flows.

(2) For meters of the general proportions shown in the sketches of Figs. 1 and 2, the value of K increases by about 8 per cent. as $\frac{p_2}{p_1}$ is diminished from 1·0 to 0·5.

(3) The value of K for meters of approximately the dimensions and proportions shown, may be taken as being given within 1 per cent. by the figures of the following Table:—

$\frac{p_2}{p_1}$

—	0·5	0·6	0·7	0·8	0·9	1·0
K	0·97	0·97	0·96	0·95	0·93	0·905

where W is taken as being given by the expression (page 596)—

$$W = 1 \cdot 099 \; K \; a_1 \; \beta \; \sqrt{\frac{p_1}{\tau_1}} \text{ lb. per second.}$$

The Paper is illustrated by 2 Figs. in the letterpress.

MEMOIRS.

John Reid Anderson was born in London on 8th January 1867, and was educated at St. Olave's Grammar School, Southwark. He attended engineering classes at King's College, London, and the City and Guilds (Engineering) College, Finsbury, during his apprenticeship, which was served with Messrs. Maudslay, Sons, and Field from 1881 to 1885, and with the late Mr. Cosmo Innes during the following eighteen months. In 1888 he was appointed engineer to the London Sanitary Protection Association, and made a speciality of drainage, water supply, and sewage disposal. In later years he entered into private practice as a consulting engineer, specializing in sanitation, heating, ventilation, etc. His death took place at Norwood, London, on 27th April 1919, at the age of fifty-two. He became a Member of this Institution in 1901, and he was also an Associate Member of the Institution of Civil Engineers.

Captain GEORGE LEONARD ANDREWS, R.G.A., was born in Calcutta on 12th November 1874. He was educated at Wesley College, Sheffield, and at the Sheffield Technical School (afterwards the Applied Science Department of the Sheffield University), and in 1895 he became a pupil with the Brush Electrical Engineering Co., Ltd. He further developed his experience in tramway construction and operation at Kidderminster, Madrid, and Hull, and in 1900 he became resident engineer to the Sunderland Corporation Tramways. Three years later he was offered the post of engineer to the Lisbon Tramways, which he held until 1905 when he accepted an offer to become general manager and engineer to the Pará Electric Railways and Lighting Co., Brazil. Some years later, after practising for a

time as a consulting engineer in Rio de Janeiro and Curityba, he accepted the offer of the important post of general manager and engineer to the Pernambuco Tramways and Power Co. He had begun constructional work when the War broke out, and he returned home to offer his services. After undergoing the necessary special training at an important coast station, he went to France, where he was in several actions. He then volunteered for service in the East, and passed six months in Egypt and Syria, after which he returned to France and was through the battle of the Somme. Subsequently he became *Liaison* Officer and Temp. Major to a Portuguese brigade of heavy artillery, and did useful work by lecturing and translating several of the gunnery books into Portuguese. He was killed in action on 3rd May 1918, at the age of forty-three, near Albert, while proceeding to an observation post. He became a Member of this Institution in 1911; and was a Member of the Institution of Civil Engineers and of the Institution of Electrical Engineers, a B.Sc. (Lond.) and a B.Eng. (Sheffield).

Henry Charles Cowdell was born in London on 11th April 1860. He served his apprenticeship with Messrs. John Stewart and Sons, Blackwall Ironworks, completing it in 1881, and during this period he attended evening technical classes at the City of London College. He then went to sea as a sea-going engineer, and served on vessels of the City and Castle Lines. Shortly after obtaining a Chief Engineer's Certificate he was appointed resident engineer of Batu Kawan Sugar Estate, near Penang, succeeding his late father in that position. He remained there until 1895, extending his practice as consultant to the owners of other sugar estates in the neighbourhood; he was also superintendent of a line of steamers running between Province Wellesley and Penang. While at Batu Kawan he greatly extended and improved the crushing machinery and sugar refining plant, installed electricity generating plant, etc., and constructed lighters up to 100 tons capacity, of native timber. He also planned and superintended the construction of three large reservoirs to provide a water supply for the district. On returning to England in 1896 he purchased

the Cradley Boiler Works, then of small dimensions. These works he improved and equipped with up-to-date machinery, so that the Cradley Boiler acquired the highest reputation. His death took place at his residence at Hagley, Worcestershire, on 31st March 1919, in his fifty-ninth year. He was elected a Member of this Institution in 1896.

Samuel Holt Donnelly was born at Swinton, Lancs., on 1st November 1875. His education was received at schools in Manchester and at the Municipal School of Technology. In 1890 he began an apprenticeship of seven years with Messrs. Turner and Sons, textile machinery works, Manchester, which was completed at the Salford Gas Works, where he afterwards worked as assistant engineer for two years. He then became chief assistant to Messrs. Rouse and Co., engineers, Manchester, and to Messrs. Luke and Co., of the same city. During this time he was also assistant instructor at the Municipal School of Technology. In 1906 he went to Letchworth as assistant engineer at the Garden City, and when the surveyor and sanitary inspector to the Hitchin Rural Council joined the Army he undertook their duties. Subsequently he was appointed assistant engineer of the Road Board at Salisbury, and in 1918 he became resident engineer at the Eastleigh Aerodrome, near Southampton, but while there he had pneumonia following influenza. Subsequently he returned to his home at Letchworth, but his death took place five weeks later, on 29th April 1919, in his forty-fourth year. He was elected an Associate Member of this Institution in 1912.

Carl Fox was born at Edgware on 10th August 1886. After receiving a general education at the Central Foundation School, Cowper Street, London, he studied for three years at the Polytechnic School of Engineering, Regent Street, and obtained Diplomas in Mechanical Engineering. In 1907 he began an apprenticeship in the shops and drawing-office of Messrs. Gilbert Gilkes, of Kendal, Westmorland, and two years later he went to Peru as assistant mechanical engineer at the mines of the Sociedad Esplotadora

de Caylloma. In 1912 he was promoted to be chief mechanical engineer of the Company, which position he held until 1916, when he went to Bolivia to take up a post as engineer to Messrs. Graham, Rowe and Co., at Oruro. This position, which he filled most efficiently, he held until the time of his death, which took place at Oruro, on 6th June 1919, in his thirty-third year. He was elected an Associate Member of this Institution in 1916.

Captain Archibald Gilbert Hamilton, R.E., was born at Folkestone on 28th November 1880. His scholastic education was received at Maidstone Grammar School, Bedford Modern School, and University College, London, after which he served an apprenticeship of three years with Messrs. Bryan Donkin and Co,. Ltd., Bermondsey. In 1900 he entered the drawing-office of Messrs. J. F. Pease and Co., Ltd., Worcester, and subsequently was engaged for a few months as draughtsman at the Queen's Engineering Works, Bedford. In 1904 he went to Burma as signal engineer to the Burma Railway Co., Ltd., Rangoon, which position he held until 1908 when he went to South America for Messrs. Saxby and Farmer. In 1915 he returned to this country to join the Army, subsequently receiving a commission in the R.O.D., R.E., France. His death took place in France on 15th February 1919, at the age of thirty-eight. He was elected a Graduate of this Institution in 1904, and an Associate Member in 1907.

John Sydney Hines was born in Birmingham on 11th February 1887. His scholastic and technical education was received at Kettering and Wellingborough, and his apprenticeship of five years was served at the works of Messrs. Salmon, Whitfield and Co., gas engineers, Kettering. On its completion he worked for over a year in the drawing-office of the same firm. In August 1909 he was engaged in the gas plant department of Messrs. Crossley Bros., Ltd., Openshaw, Manchester, becoming assistant to the chief engineer. In 1916 he was appointed lecturer in Geometry and Machine Drawing for evening classes at the College of Technology, Manchester. His health broke down, and although he was able

to keep up his college work for a time, he developed bronchitis, and his death took place at Kettering on 30th April 1919, at the age of thirty-two. He was elected a Graduate of this Institution in 1911, and an Associate Member in 1915.

Robert Hiram Jackson was born in Manchester on 24th October 1858. He was educated at Lymm Grammar School, and served an apprenticeship of five years with Messrs. W. and J. Galloway, Knott Mill, Manchester, which was preceded by one year's training in telegraphic engineering under Mr. John Doherty, Manchester. At the age of twenty-one he was employed as a journeyman fitter for Messrs. Emmerson and Murgatroyd for eighteen months, and then after a short time with Messrs. Mather and Platt, Salford, he returned to Messrs. W. and J. Galloway as fitter and erector. Three years later he acted as deputy to Mr. Arthur Carey, manager of machinery sections of the Inventions Exhibition in London, 1885. In the following year he acted in a similar capacity at the Liverpool Exhibition, and in 1887 at the Royal Jubilee Exhibition, Manchester, he held the appointment of Superintendent of the Machinery Section. In June 1888 he joined the staff of Messrs. Schäffer and Budenberg (now the Budenberg Gauge Co., Ltd.), Manchester, as engineer and representative, with whom he remained until his death. In 1918 he was elected a director of the Company. His death took place, after a long illness, at his residence in Manchester, on 26th June 1919, in his sixty-first year. He became an Associate Member of this Institution in 1898.

Captain John Baxter Jarvis, I.O.M., R.A.O.C., was born in London on 29th June 1879. He was privately educated, and attended the Crystal Palace School of Engineering, subsequently working as a fitter at Messrs. Thornycroft's works at Chiswick. In 1898 he became assistant engineer to Messrs. J. H. Holmes and Co., of Newcastle-on-Tyne, and five years later started in business in Birmingham as motor and general mechanical engineer. In 1908, owing to serious illness, he had to close the business, and went for a trip round the world. On his return in 1911 he

started work in Westminster as advisory motor engineer, and was appointed an inspecting engineer for the Automobile Association and Motor Union. He invented a controller for simplifying the valve mechanism for internal-combustion engines, which rendered the engine self-starting. At the beginning of the War he gave much voluntary work in testing cars, etc., and in February 1915 he was appointed an Inspector of Ordnance Machinery, being commissioned as Lieutenant. In July of the same year he was sent to France and was given the command of the 1st Army Heavy Mobile Workshop. He invented a gun-mounting, in collaboration with Lieut. Clark, R.A., which was used with success at the Front. Having been badly gassed in May 1916, he returned to England and resumed home service, being appointed assistant I.O.M. for Dover until his Major was sent to France, when he took his place, and received his Captaincy in 1917. In spite of several attacks of fever, he carried on with great energy through all the period of the air raids. In October 1918 he was moved to London Headquarters, Eastern Command, and was asked to remain in the Service after the armistice. He had lately been appointed to carry out some special work, but he contracted septic pneumonia and died at the 3rd London Military Hospital on 10th April 1919, in his fortieth year. He was elected an Associate Member of this Institution in 1915.

Alfred Henry Kell was born at Woolwich on 24th October 1858, and received his general education at the Woolwich Arsenal schools. In 1874 he began an apprenticeship of seven years at Woolwich Arsenal, and on its completion he went to Venezuela as fitter on the Bolivar Railway. Four years later he became foreman of the running shed on the same railway, subsequently becoming general foreman of the fitting shop and running shed. In 1898 he returned to England and worked as a mechanic at Woolwich Arsenal for three years, after which he again went to Venezuela as works foreman at the La Guaira Harbour Works, being subsequently appointed engineer to the Harbour Corporation. This position he held until his death, which took place at Curaçao,

West Indies, on 25th March 1919, in his sixty-first year. He was elected a Member of this Institution in 1917.

Carl Rudolf Lewin Lemkes was born at Minden, Prussia, on 2nd May 1853, and was educated at the Grammar School and Imperial High School of his native town. He then had a two-years' apprenticeship in a commercial firm, but having an inclination towards engineering he became works clerk to Messrs. Schäffer and Budenberg, of Magdeburg, in 1873. Shortly afterwards he was transferred to the Manchester branch of the firm as assistant manager, and since 1882 he had held the appointment of district manager in Glasgow, being sole representative for Scotland and Ireland. His death took place in Glasgow, after a brief illness, on 5th July 1919, at the age of sixty-six. He was elected an Associate of this Institution in 1896.

Wilfred James Lineham was born at Leeds on 17th December 1858. After the usual primary and secondary education he passed the B.Sc. Examination in Engineering at the University of London, and obtained a studentship at the Normal School, now the Royal College of Science. He served his time from 1871 to 1879 in the shops of Messrs. John Fowler and Co., and was engaged there as draughtsman till 1881, when he took up a similar position at the works of Sir W. G. Armstrong, Mitchell and Co., Elswick, and again from 1887 to 1890. He was leading draughtsman at Messrs. R. and W. Hawthorn, Leslie and Co., Newcastle-on-Tyne, from 1884 to 1887. From 1880 onwards he had also been engaged in teaching engineering subjects at Leeds, Dewsbury, Wakefield, and at the School of Science and Art, Newcastle-on-Tyne, now the Rutherford Technical College. In 1890 he was appointed Professor of Engineering and Mechanical Science at the Goldsmiths' Company's Technical Institute, New Cross, London, which position he held until his death. On the outbreak of the War he was in Bavaria, but managed to reach home after a fortnight's detention and hardship. In July 1915, under the London County Council Education Department's scheme for using the Technical School

Workshops of London for war service, Mr. Lineham organized that at Goldsmiths' Institute with great success for the manufacture of gauges for fuses and shells. In 1916–17 he undertook the manufacture of screw-pitch measuring machines to the designs supplied by the National Physical Laboratory, and in the following year, owing to the great demand for aeroplanes and machine-guns, position gauges were turned out instead of the simpler form of gauge. The features of the screw-gauge work were the success obtained on small sizes and the method of producing hardened steel screw-gauges without lapping. In November 1918 his health broke down from overwork, and he was ordered a complete rest. His death took place suddenly at Brighton on 17th April 1919, at the age of sixty. He was very versatile, being an able musician, and his paintings were frequently shown at the Royal Academy. He became a Member of this Institution in 1890; he was also a Member of the Institutions of Civil Engineers and Electrical Engineers, and was on the Faculty of Engineering and the Board of Civil and Mechanical Engineering of the University of London. He was the Author of various Engineering Articles, Lectures, etc., and brought out a standard "Text Book of Mechanical Engineering."

Engineer Vice-Admiral Baron Jiro Miyabara, I.J.N., was born at Surugadai, Yeddo (now Tokio), on 7th July 1858. He entered the Naval School at Tokio in 1873, and two years later was sent to England to study marine engineering, when he took the three years' course at the Royal Naval College, Greenwich. He also received practical training at the works of John Elder and Co., Glasgow, and at Barrow-in-Furness at the time when the "City of Rome" was being built. In 1883 he returned to Japan, and became Engineer-Lieut. (Junior Grade), when he was sent again to England to order and inspect the construction of engines for two fast cruisers. Three years later he was appointed head designer of the Yokosuka Dockyard, which position he held until 1893, when he was sent to inspect the engines for the battleships "Yoshima" and "Fuji." During this time he brought out the Miyabara water-tube boiler. The degree of Doctor of Technology was conferred upon

him in 1899, and in the following year he was promoted Engineer Rear-Admiral and Engineer-in-Chief of the Japanese Navy. The Emperor conferred upon him in 1904 the Order of the Rising Sun, 2nd class, for his water-tube boiler invention, and in 1906 the Order of the Golden Kite, 3rd class, for his services during the Russo-Japanese War. In the same year he was promoted Engineer Vice-Admiral, and was created Baron in 1907. He retired from the service in 1908, and subsequently was chosen as a Member of the House of Peers. As early as 1905 he adopted the Curtis turbine for armoured cruisers, which had at that time only been used in merchant vessels. He started an Engineering Society on his retirement, to promote engineering knowledge among the young Japanese, and installed a small laboratory at his own expense. He rendered valuable services to the Allied cause, and was Chairman of the Council of the British Society in Japan. His death took place at his residence near Tokio, on 15th January 1918, in his sixtieth year. He was elected a Member of this Institution in 1897.

Alexander Neil was born at Govan, near Glasgow, on 15th January 1840. He served an apprenticeship with Messrs. Smith and Rodgers, shipbuilders, Govan, and was one of the original foremen of John Elder and Co., now the Fairfield Shipbuilding and Engineering Co., Ltd. In 1871 he became shipbuilding manager to Messrs. Cunliffe and Dunlop, of Port Glasgow, leaving ten years later to join the firm of Messrs. W. and A. C. Russell and Co., ironfounders, Pendleton, Manchester. In 1892 his firm amalgamated with Messrs. Thomas Fletcher and Co., of Warrington, when he became vice-chairman, and later Chairman of the Company. For a time he was also Chairman of the Engineering Section of the Manchester Chamber of Commerce. His death took place at Colwyn Bay on 13th June 1919, at the age of seventy-nine. He was elected a Member of this Institution in 1902.

Charles Temple Orme was born in London on 6th February 1883. He was educated at University College School from 1890–97, and at the Acton and Chiswick Polytechnic. He then studied at

the City and Guilds of London Technical College, Finsbury, during which period he served an apprenticeship of two and a half years at the Clerkenwell Engineering Co. In November 1904 he went to the Pulsometer Engineering Co., Reading, where he was engaged on working out details and perfecting the design of the Pulsometer type-setting and distributing machines. Five years later he was engaged by the Daimler Motor Co. at Coventry and at Reading until 1911, when he became designer of automatic calculating machines under the Barr-Bell Syndicate. In 1914 he went to Galicia as engineer with the Galician Oil Fields, and on his return to England in the following year he entered the workshops of the Munitions Invention Department at University College, London, being for some time in charge of the office and workshops. After the war, he was arranging for the removal of the Department to works at Chiswick, which had previously been used for the manufacture of secret war munitions, and while there he received into his system a poisonous irritant due to the nature of the dust inhaled. This caused his death which took place at Acton, London, on 26th June 1919, at the age of thirty-six. He was elected a Graduate of this Institution in 1905, and an Associate Member in 1911.

William Henry Potter was born at Nottingham on 15th December 1860. He was educated at the then Radcliffe Grammar School, and at the age of sixteen was apprenticed to Mr. William Benson, engineer, of Nottingham. During his apprenticeship he attended Science and Art classes at the Mechanics' Institute, gaining a Whitworth Scholarship in 1880. In the following year he was employed as draughtsman to the Corporation of Liverpool. He returned to Nottingham eighteen months later, and obtained a position as draughtsman and foreman of the erecting shop at Messrs. H. S. Cropper and Co., printing-machine manufacturers, with whom he worked until 1886. Subsequently he was engaged as draughtsman at Messrs. Goddard and Massey's works for three years, during which time he was employed on the design of wire-netting machines. In 1889 he undertook the abridging of patent specifications, having previously qualified for this position, and in

1893 he passed the Final Examination of the Institute of Patent Agents. From that time until his death he was actively engaged in patent and consulting engineering work, specializing in lace and hosiery machines and manufacture. From 1883 to 1895 he was a lecturer in Engineering at the University College, Nottingham and at Derby. His death took place at Nottingham on 2nd May 1919, in his fifty-ninth year. He became a Member of this Institution in 1890.

John William Strutt, third Baron Rayleigh, P.C., O.M., D.C.L., LL.D., F.R.S., was born at Langford Grove, Essex, on 12th November 1842. He was educated at Trinity College, Cambridge, and was Senior Wrangler and Smith's Prizeman in 1865. Twelve months later he was elected to a Fellowship at Trinity College, which he retained for four years. In 1873 he was chosen a Fellow of the Royal Society, and succeeded Professor Clerk Maxwell as Cavendish Professor of Physics in 1879, which post he held until 1884. During that period he carried out valuable investigations for the Committee of the British Association to improve the construction of the practical standards for electrical measurement, in which he was assisted by Professor Schuster and Dr. Glazebrook. In 1884 he served as President of the British Association at Montreal, and soon after his return from Canada he was elected one of the Secretaries of the Royal Society, a position he held until 1896. In 1887 he became Professor of Natural Philosophy at the Royal Institution in succession to John Tyndall, and held this position until 1905, when he became President of the Royal Society. Three years later the University of Cambridge elected him Chancellor in place of the late Duke of Devonshire. The Nobel Prize was awarded to him 1904. He held the Copley Medal, was a Knight of the Prussian Order Pour le Mérite and of the Légion d'Honneur, and was made a Privy Councillor in 1905. He was Chairman of the Treasury Committee which recommended the establishment of the National Physical Laboratory, and subsequently presided over its Executive Committee. He acted as Chief Gas Examiner under the Metropolitan Gas Acts, and sat on

the Board of Trade Committee which reported on the methods of testing gas. His best known and most remarkable achievement was the discovery of argon in the atmosphere, which was announced in 1894, and in the later stages of his investigation he was associated with the late Sir William Ramsay. In recognition of the value of his discoveries, Lord Rayleigh's name was included in the original list of twelve upon whom King Edward VII conferred the Order of Merit in 1902. He was nominated an Honorary Life Member of this Institution in 1896. His death occurred at his Essex home, Terling Place, near Witham, on 30th June 1919, in his seventy-seventh year.

Richard David Sanders was born at Leamington in 1842. He was educated partly at the Warwick Grammar School and partly by private tuition in mathematics. In 1859 he became an articled pupil in the locomotive department of the London and North Western Railway at Wolverton, under the late Mr. J. E. McConnell, and was subsequently employed on the Southern Division of the railway from London to Stafford. Upon the retirement of Mr. McConnell, he accompanied him to London and acted as assistant in his business as consulting engineer for some little time, but being desirous of acquiring more practical experience, he entered the workshops of the Midland Railway at Derby under Mr. Matthew Kirtley, of which railway his uncle, Mr. Joseph Sanders, was for some years general manager. In 1864 he became assistant in the works of Messrs. Beyer Peacock, of Manchester, by whom he was recommended for, and obtained in 1866, the appointment of assistant locomotive superintendent on the Great Indian Peninsula Railway, being placed in charge of the Southern Division of that line from Bombay to Sholapore. He was afterwards sent to other parts of the line, and then promoted and given the entire management of the rolling stock departments, both as regards repairs, maintenance, workshops, etc., together with the superintendence of the water supply over the whole line of 1,280 miles. Owing to a serious accident on the Bhore Ghaut incline he was deputed to carry out an exhaustive series of

experiments to ascertain the most effective brake-power for future use. In connexion with this inquiry he was also employed by the Government of India to inquire into and consider the system employed on the Ceylon Railway, upon the similar incline between Colombo and Kandy. It was while engaged upon these experiments that he conceived the idea which ultimately led to his invention of the automatic vacuum brake, now almost universally used upon English railways, and upon all the railways in the Colonies. In 1873, while in Bombay, he fitted up a train with ejector and vacuum pipes as a means of communication between drivers, passengers, and guards. This train ran between Bombay and the foot of the Ghaut inclines for some time, and was almost identical with the apparatus now being introduced upon some of the English railways. He also turned his attention to the comfort of passengers travelling under tropical conditions, and invented and introduced a system for cooling the interior of passenger coaches, by which the temperature was reduced about 20° F.; fifty carriages were fitted up with his system and ran for some years between Bombay and Calcutta.

In 1875 Mr. Sanders left India and accepted an appointment as managing engineer to the firm of James Watt and Co. at Soho, where he remained about five years, during which time he built and erected many important pumping engines of large size for the South Staffordshire Water Works Company, and the Birmingham Water Works, the sewage engines on the Victoria Embankment, pumping engines for Singapore and other places. He also had the management of the Soho mint. Finding that the automatic vacuum brake demanded a great deal of attention, he resigned his position at Soho, and for some time devoted all his time to the development of his inventions, and attending to the details consequent upon the application of his brake to the Great Western, Lancashire and Yorkshire, and Midland Railways. In 1884 Mr. Sanders was specially selected by Sir Alexander Rendel and the directors of the Mexican Railway to investigate thoroughly the working of that line in every department, and his exhaustive report gained a special vote of thanks from the Chairman and

Board of that railway. The records of the Patent Office bear striking testimony to the many and various directions in which his inventive genius found scope for unusual activity, and amongst other fields of study he devoted a considerable amount of attention to the electro-deposition of metals, one of his inventions relating to a method of depositing copper directly into the form of high-conductivity wire. After many years' work he succeeded in perfecting his invention, and the Copper Works at Queenborough were established for exploiting it; and a considerable amount of copper wire was deposited direct from the rough ingots with a conductivity of from 102 to 103 per cent. as compared with Matthiessen's standard. During the latter part of his life Mr. Sanders carried on a practice as consulting engineer, and was largely occupied in valuing the rolling stocks of nearly all the railways in England, and giving expert evidence thereon in rating appeals. In his early years Mr. Sanders became interested in military matters, and was a member of the 19th Lancashire Artillery Volunteer Corps. During his residence at Blackheath, London, the frequent air raids probably caused his mind to revert to his early artillery experience, for his last recorded invention, in 1916, related to improvements in the manufacture of shells. His death took place at Blackheath on 11th May 1919, at the age of seventy-seven. He became a Member of this Institution in 1871, and in 1878 he read a Paper on Continuous Brakes, advocating the automatic action, which condition was subsequently required by the Board of Trade.

George Stewart was born at Motherwell on 21st September 1859. After receiving his early education locally, he served an apprenticeship of seven years at the locomotive works of the Caledonian Railway Co., and in 1882 went to America, where he was employed at the locomotive works of the Miama Railway Co., Cincinnati, for two years. On his return to Scotland he worked at the Coltness Iron Works, Newmains, for a few months, and then in November 1884 he went to Siam to take charge of Messrs. Kim, Ching and Co.'s rice mills at Bangkok. In 1894 he started in

business as consulting engineer for the design and erection of rice and saw mills, and became superintendent engineer for various mills and a director of several local railway, tramway, and steamship companies. In 1906 he returned home, and his death took place in Glasgow on 9th February 1919, in his sixtieth year. He became a Member of this Institution in 1903.

Albert Vickers was born in Sheffield on 16th September 1838. He was educated at Sheffield and at Hameln-on-the-Weser, and entered his father's works at Millsand, near Sheffield, in 1854, where his brother, the late Colonel T. E. Vickers,* was in charge. Shortly afterwards he proceeded to the firm's offices at Boston, U.S.A., in order to gain experience of their American trade, but owing to the closing of the business because of the financial crisis, he returned to Sheffield in 1857. The old works proving too small, the River Don Works were constructed in 1863–4, and the two brothers began that close association—the one a great metallurgist and the other a great commercial force—which has so greatly influenced the destinies of the Company. In 1883 Sir (then Mr.) Hiram Maxim introduced to Mr. Vickers a proposal for making a gun to load and fire itself, with the result that the Maxim Gun Company, with Mr. Vickers as chairman, was formed in 1884, and amalgamated with the Nordenfeldt Company in 1888. The Vickers Company, who had already started manufacture of heavy guns and armour, absorbed the joint concern in 1896, and in the following year purchased the Naval Construction Company with their shipyard and engine works at Barrow-in-Furness, the object being to carry out the policy enunciated by Mr. Albert Vickers of enabling the firm to complete a warship for service within their own organization. About 1901 they formed the Electric and Ordnance Accessories Co. (now known as Wolseley Motors, Limited) to carry on special branches of the Company's work. In 1903 there was acquired a part share of the Chilworth Powder Works, and in 1906 of the Whitehead Torpedo Works. Mr. Albert Vickers succeeded his brother as chairman of Vickers, Ltd. (the

* Proc. I.Mech.E., 1915, page 809.

name ultimately adopted) in 1909, having been a managing director for many years. He resigned the chairmanship on his eightieth birthday in 1918. For his services to foreign countries he was awarded several decorations, including the Knight Grand Cross of the Order of Naval Merit of Spain and the Order of the Rising Sun of Japan. His death took place at Eastbourne on 12th July 1919, in his eighty-first year. He became a Member of this Institution in 1865, and he was an Associate of The Institution of Civil Engineers and of the Institution of Naval Architects.

John Begby Williams was born in Naples on 7th July 1858. His apprenticeship was served at Messrs. Palmer's Engineering Works at Jarrow-on-Tyne; and on the establishment of the Central Marine Engine Works by Messrs. William Gray and Co. at West Hartlepool in 1882 he joined the staff, subsequently becoming assistant manager. This position he held at the time of his death, which took place suddenly at West Hartlepool, on 23rd April 1919, in his sixty-first year. He became a Member of this Institution in 1884.

John Hudson Wilson was born at Eastwood, Notts, on 14th September 1896. His general education was received at the New Eastwood C. C. School, and at the age of eleven he went to Heanor Technical School, which was followed by two years at the Nottingham University College. In September 1913 he became a pupil at the locomotive works of the Midland Railway at Derby, and two years later he joined the Royal Naval Air Force, spending two years in France, having the rank of Air Mechanic, 1st class. In February 1919 he obtained his discharge, and reached Clipstone Camp on 1st March for demobilization, but he was suddenly taken ill, and succumbed from double pneumonia on 4th March 1919, in his twenty-third year. He became a Graduate of this Institution in 1917.

The Institution of Mechanical Engineers.

PROCEEDINGS.

OCTOBER 1919.

The FIRST ORDINARY GENERAL MEETING of the Session was held at The Institution of Civil Engineers, London, on Friday, 24th October 1919, at Six o'clock p.m.; HENRY DAVEY, Esq., *Vice-President*, in the Chair.

The CHAIRMAN, in opening the Meeting, said it was with great regret that he took the Chair owing to the illness of the President, Dr. Edward Hopkinson. He had had to do so once before, and it was with deep regret that he did so again. He called upon the Secretary to read a letter which had been received from the President.

The SECRETARY read the following letter:—

FERNS, ALDERLEY EDGE, CHESHIRE.
October 23rd, 1919.

DEAR MR. WORTHINGTON,

It is with very great regret that I have to ask you to explain to the Members of the Institution who attend the opening Meeting of the Session to-morrow that, under medical advice, I am unable to be present, and to express my great disappointment that I cannot personally address them. I am greatly indebted to my predecessor, Mr. Longridge, for offering to read my Address for me. I congratulate members on the prospect of early complete re-entry into our own House, and am glad to think that the strain put on the Staff by the occupation of temporary and incommodious offices is now terminated.

Yours sincerely,
EDWARD HOPKINSON.

The Chairman said it was his painful duty to announce the decease of Lord Rayleigh, O.M., F.R.S., who was an Honorary Life Member of the Institution since 1896.

The Minutes of the previous Meeting, held on 30th May, were confirmed and signed.

The Chairman announced that the Council had nominated the following three Honorary Life Members, all of whom had accepted the nomination :—

H.R.H. The Prince of Wales, K.G.
Sir Richard T. Glazebrook, C.B., F.R.S.
The Hon. Sir Rajendra Nath Mookerjee, K.C.I.E.

The Chairman announced that, to fill the vacancy caused by the resignation of Sir Dugald Clerk, K.B.E., as a Vice-President, which he was sure the members regretted, the Council had appointed Captain H. Riall Sankey, C.B., R.E. ; and to fill the consequent vacancy Mr. Christopher W. James (of Leeds) had been appointed a Member of Council. Mr. David E. Roberts had also been appointed a Member of Council, in place of Mr. Robert Matthews, who had resigned.

All the gentlemen appointed by the Council would, under Article 25, retire at the next Annual General Meeting, when they would be eligible for election.

The Chairman announced that the following seventy-five Candidates had been duly elected on 27th June :—

MEMBERS.

Anderson, James Edward,	Derby.
Beatty, Racster Stephens,	Windhuk, S.W. Africa
Findlay, James,	Wolverhampton.
Hill, Charles Harold,	Negapatam.
Lomas, Robert,	Rosario, Arg. Rep.
Prestige, Sydney Ernest,	London.
Robinson, John Eteson,	Sheffield.
Sutcliffe, Tom,	London.
Sykes, Godfrey Glenton,	Tucson, U.S.A.

ASSOCIATE MEMBERS.

Barker, Norris, Lieut., R.N.V.R., . .	Portsmouth.
Bisset, David, ...	Singapore.
Burdis, Addison Stanley, Lieut., R.E. (T.),	South Shields.
Coppock, Norman Septimus, . . .	Cardiff.
Crawford, John Scott, Capt., R.A.S.C., .	B.E.F., France.
Dawson, James Tweedie, Capt., R.E., .	Dalkeith.
Dimbleby, Thomas Edward, . . .	Loughborough.
Evans, William Gwynne, . . .	Swansea.
Fowles, Samuel Henry, ...	Hebburn-on-Tyne.
Hailstone, John Edward, . . .	Cossipore.
Hall, Horace Frank, ...	Woolwich.
Hare, Arthur Rufus, ...	London.
Harris, Sidney, ...	Cardiff.
Hayward, Russell Dallas, Lieut., I.A.R.,	Bombay.
Hetherington, John, ...	Barrow-in-Furness.
Higgins, Mark, Lieut., R.A.O.C., I.O.M., .	B.E.F., France.
Horsburgh, Lambert Gordon, . . .	Leeds.
Hudson, Russell, ...	London.
Humphreys, Henry, ...	London.
Irving, Benjamin, ...	London.
Issels, Henry Gordon, ...	Dublin.
Kemp, James Pattison, ...	Birmingham.
Le Manquais, Frederick Valentine, .	London.
Littler, Linnæus, ...	Birmingham.
Lockwood, Arthur, ...	Beddgelert.
Lynes, Frederick John, Lieut., R.A.F., A.I.D., ...	Leamington.
Lyth, Cyril John, ...	Coventry.
McVey, John, ...	High Wycombe.
Magill, Michael Francis, . . .	London.
Marshall, Sydney Charles, . . .	London.
Morales, Eusebio, ...	Manila.
Morton, Robert Ebenezer, . . .	Glasgow.
Parnell, John Louis, ...	London.
Phillips, Ernest George, . . .	Nottingham.
Pile, William Devereux, . . .	Dublin.
Ponsford, George Lowe, ...	London.
Price, Harry Salisbury, ...	Darlaston.
Richards, William, ...	Stroud, Glos.
Roberts, Arnold Mitchell, . . .	Crewe.
Sanderson, John George, Capt., R.A.O.C., M.C., ...	B.E.F., France.
Sheel, Harold, Capt., ...	London.
Smith, Arthur William Bertram, . .	London.
Stevenson, George Washington, Capt., R.E.,	Norwich.

Thompson, Fenton Gordon, Lieut., Tank Corps, ...	B.E.F., France.
Vallings, Geoffrey Harold Valentine, Capt., R.A.S.C., I.M.T., . . .	B.E.F.
Weller, James, Eng. Lieut., R.N.R., .	London.
Whitaker, Alfred Henry, . . .	Highbridge.
Willett, Alfred John Cecil, . . .	Manchester.
Wise, Ivor Charles, Staff Captain, R.E., .	B.E.F., France.
Wood, Donald Shipton, Lieut., R.E. (T.), .	B.E.F., France.
Woodford, Harry, ...	Warrington.
Wylie, Richard George, ...	Liverpool.
Yates, David Henry, ...	Bolton.
Young, Harry Clarance, . . .	Birmingham.

ASSOCIATES.

Brownlie, David, ...	Manchester.
Hughes, Harry Halcomb, Eng. Sub.-Lieut., R.N.R., ...	Dover.

GRADUATES.

Bishop, Harold, ...	London.
Brooks, Cyrus Norman, ...	Sanderstead.
Clifford, Stanley, ...	Twickenham.
Hardy, George Dudley, ...	Birmingham.
Holst, Thorodd, ...	Derby.
Marks, Cecil Stanley, ...	Cape Town.
Marsh, Walter Edgar, ...	Birmingham.
Miles, John Edwin, ...	Bath.
Simonson, William Foster, . . .	London.
Stavridi, Alexander Gregory, . .	London.

The Chairman announced that the following 210 Candidates had been duly elected at the present Meeting:—

MEMBERS.

Abbott, Frank Edmund, ...	London.
Ashworth, Wilfred Adam, . . .	London.
Cooper, Harry, ...	Leeds.
Everett, Edgar Isaac, ...	London.
Graystock, Albert, ...	Stoke-on-Trent.
Hall, William, ...	Kilmarnock.
Halliwell, Reginald Francis, . .	Rugby.
Lamb, Harry Cromwell, . . .	Manchester.

MacGregor, James, Lieut.-Col., C.M.G., R.E., ...	Calcutta.
Martin, William Edward, . . .	Stamford.
May, Hubert, ...	London.
Miller, Stephen Charles, . . .	Monifieth.
Moir, William, ...	Bombay.
Musgrave, Bernard, Lieut.-Col., . .	London.
Neilson, William Hardcastle, . .	Karachi.
Paul, Denis, Colonel, C.M.G., C.B.E., R.A.O.C., ...	B.E.F., France.
Pearson, John Cox, Eng. Com., R.N., .	Edinburgh.
Pearson, Robert John Addison, O.B.E., .	Erith.
Pettman, Allan, Eng. Lieut.-Com., R.N., .	Osborne.
Robinson, George Herbert, M.Sc., . .	Birmingham.
Shannon, David McCrorie, . . .	Birkenhead.
Smith, Sydney, ...	Briton Ferry.
Stanton, Thomas Ernest, D.Sc., F.R.S., .	Teddington.
Sumner, Sydney, ...	Preston.
Tassell, Arthur John, ...	Stoke-on-Trent.
White, Arthur Stephen, . . .	Bombay.
White, Bruce Gordon, Major, R.E., .	London.

ASSOCIATE MEMBERS.

Abbey, Arthur, ...	Woolwich.
Adamson, Henry, ...	Preston.
Alltree, William George, Eng. Lieut.-Com., R.N., ...	London.
Anderson, George Frederick, . . .	Manchester.
Anderson, James Alexander, . . .	London.
Araujo, Arturo, ...	San Salvador.
Arnold, Arthur, Eng. Lieut., R.N., . .	London.
Ayre, Albert Oswald, ...	Calcutta.
Baines, Joseph Caress, ...	Sheffield.
Baldwin, Sydney, ...	London.
Bambridge, Hugh Gordon, Lieut.-Col., R.E.,	Cairo.
Battersby, Samuel Terry, . . .	Northwich.
Bayley, William Lloyd, ...	Darlaston.
Bean, Harry Edward, Capt., A.I.F., .	Melbourne.
Bennett, William Alfred, . . .	Birmingham.
Berk, Frederick William, . . .	Bradford.
Berryman, Thomas, ...	Camborne.
Bindloss, Allan Kell, ...	Paisley.
Blick, Charles William John, . .	Birmingham.
Bowman, James, ...	Woolwich.
Bradshaw, Harry, ...	Calcutta.

Branch, Arthur Charles, . . .	London.
Bridge, Arthur, ...	Limerick.
Browne, Malcolm Frank, Captain (Tech.), R.A.F.	London.
Burgess, John Henry Burton, Major, R.A.F., ...	London.
Bury, Samuel, ...	Bolton.
Buxton, Richard Henry,. . . .	London.
Campbell, George Albert, . . .	S. Farnborough.
Causer, Donald Stuart, Captain, R.G.A., .	London.
Cochran, Oliver, ...	Nottingham.
Coe, Lewis Archibald, ...	Newport, Mon.
Collis, Sydney Carr, ...	Burton-on-Trent.
Connolly, Alfred William, . . .	Ishapore, India.
Conti, Albert, ...	Milan.
Coston, Edward Percy, ...	Liverpool.
Cowderoy, Percy, ...	London.
Davies, Douglas Hall, ...	Kuala Lumpur.
Dawes, Cecil St. Hugh, ...	Swanage.
Dickson, John Michael, Captain, R.A.O.C.,	Portsmouth.
Duncan, James Berwick, ...	London.
Edwards, Edward, ...	Bombay.
Elbourne, Edward Tregaskiss, M.B.E., .	London.
Fitt, Arthur John Henry, . . .	London.
Forster, John, ...	North Shields.
Fowler, Samuel Henry Milne, . .	Bellingen, N.S.W.
Franklin, Arthur, ...	London.
Gabriel, John Beresford Stuart, Capt., R.E. (T.), ...	London.
Goldsmith, Herbert Stephen, . . .	Newcastle, N.S.W
Goodman, Reginald Colmer, . . .	Harbin.
Gordon, John Beaton, ...	Woolwich.
Gorman, Frederic George, . . .	London.
Goskar, Thomas Augustus, . . .	Swansea.
Gray, Thomas Campbell, ...	Mysore.
Green, Hugh Stanley, Lieut., R.A.F. (Tech.), ...	Lahore.
Haas, Adolph Louis, . . .	London.
Haskew, Frederick John Thomas, Capt., R.A.O.C., I.O.M., ...	Woolwich.
Haswell, Henry, ...	Sunderland.
Hazell, Robert Lufkin Keable, . .	Colchester.
Henderson, William, ...	Bombay.
Hetherington, John, ...	London.
Hey, George, ...	London.
Hitchens, Archibald William, . .	Cape Colony.
Homewood, James Blum, ...	London

Jack, Harry Robertson, ...	Huddersfield.
Jackson, Harry Yule Vivian, Capt., R.E., M.C., ...	South Persia.
Jackson, William Valant, Lieut., R.E. .	Nottingham.
Jenkins, David Walter, ...	Aberavon.
John, Wesley Ernest, ...	Richmond, Surrey.
Johnson, John David, ...	Gainsborough.
Jones, Edgar Price, ...	Manchester.
Jones, Walter Charles, ...	London.
Jordan, Albert Edward, ...	Bombay.
Kernick, Henry Williams, Captain, R.E. .	Singapore.
Kerr, Robert Taylor, ...	Togoland.
Kirkham, James, ...	Woolwich.
Lamb, Frederick Briddon, Major, Tank Corps, ...	London.
Laws, Frederick William Derwin, . .	Sumatra.
Leal, William Patrick, ...	Tavoy, Burma.
Leonidhopoulos, Apostolos, . . .	Halifax.
Lewin, Herbert William, Major, R.A.S.C.,	London.
Lewis, Ernest, ...	Glasgow.
Lightfoot, Henry Ewbank, . . .	London.
Lloyd, Charles Graham, . . .	Cardiff.
Logie, William, ...	Paisley.
Love, Henry, ...	London.
Lygo, George Ernest, ...	London.
McGlashan, Thomas Martin, . . .	Kilmarnock.
Macnair, James Leadbetter, . . .	Singapore.
MacWhirter, George Edward, . .	Antofagasta.
Marigny, Hubert George, . . .	London.
Maseyk, Arthur Ernest William, . .	Birmingham.
Matthews, Herbert Harry, . . .	Derby.
Meares, Frederick Thomas Devenish, .	Sydney.
Mein, Owen Coore, ...	Cardiff.
Mills, George Dagan, ...	London.
Milsom, Harry George, ...	London.
Minty, Alexander, ...	Ipswich.
Newman, Arnold Wilfrid, . . .	London.
Nicholson, Samuel Gordon, . . .	Birmingham.
Osborn, Harold, ...	London.
Pagett, Harry, ...	Birmingham.
Parker, Frederick Thomas, Major, R.M.E.,	London.
Pease, William Henry, ...	London.
Peter, John Francis, Capt., A.O.D., I.O.M.,	Woolwich.
Phythian, Thomas Ewart, . . .	Leeds.
Pirie, Hugh Lewis, Major, R.A.O.C., .	Archangel.
Pounder, Cuthbert Coulson, . . .	Belfast.
Powell, Stanley Gordon, . . .	Manchester.

Purnell, Charles William John, . .	Wolverhampton.
Ramsay, Thomas, ...	Berbice.
Reid, John Robert, ...	Manchester.
Rothwell - Jackson, James Frederick Marshall, ...	Bolton.
Rowan, David, ...	Liverpool.
Ryder, Percy George, ...	Gravesend.
Salter, William John Samuel, . .	London.
Sayers, George, ...	Malacca.
Seddon, James, ...	Dublin.
Small, Francis Gordon, ...	Bedford.
Smith, Alexander Clapperton, . .	Watford.
Smith, Harold William, . . .	Barrow-in-Furness
Smith, Harry George, ...	Sheffield.
Smith, Sydney Archbold, Capt., R.E. (T.), M.C., ...	Leeds.
Stevenson, Donald, ...	High Wycombe.
Steward, William Arthur Briault,. .	London.
Stewart, James, Capt., ...	London.
Sumner, Bernard Stedman, . . .	Port Said.
Swanston, Marshall, ...	Manchester.
Sylvester, Cyril, ...	Manchester.
Tattersall, William, ...	Stockport.
Taylor, Arthur Edward, . . .	Runcorn.
Tenhamm, Adolphe, ...	London.
Thomas, Frederick Arthur, . . .	Croydon.
Thompson, Samuel Henry, . . .	Llansamlet, Glam.
Thomson, Thomas Muir, ...	Tonbridge.
Tinsley, Charlie, ...	Stalybridge.
Tree, Benjamin Fergusson, . . .	Gateshead-on-Tyne
Vale, Albert Victor, ...	Birmingham.
Van Vossen, Armand Christiaan Jan Vreedenberg,.	New York.
Walker, William John, ...	Manchester.
Ward, Henry St. John, ...	Bloemfontein.
Warwick, George, ...	Burton-on-Trent.
Whaley, Ralph Stanley, . . .	Birmingham.
White, Frederick Wallis, . . .	London.
Wilkinson, Arthur Rowland, . . .	Bombay.
Williams, Joseph Peter Macardle, . .	Dundalk.
Williams, Thomas George Turner, . .	Liverpool.
Williams, Walter Lawrence, . . .	Birmingham.
Wolfenden, Ralph, M.B.E., M.Sc., . .	London.
Woodcock, Francis Stanley, . . .	Bradford.
Wright, Arthur John, Capt., R.A.O.C., I.O.M., ...	B.E.F., France.
Wright, John, ...	Manchester.

ASSOCIATES.

CHESTER, WILLIAM EWART, . . .	London.
DRURY, ARTHUR WILFRED NICHOLAS, . .	London.
MANLEY, REGINALD HARWOOD, Major, R.A. (ret.), ...	Enfield Lock.
MAURICE, FRANK JULIAN, ...	London.
ROBINSON, NORMAN, ...	London.

GRADUATES.

BAILY, EDGAR WILLIAM, ...	Huddersfield.
BIRCH, HARRY LESLIE, ...	Birmingham.
BRIGGS, HAROLD, ...	Leicester.
COE, DAVID KENNETH ARCHIBALD, . .	Newport, Mon.
DAVEY, NORMAN, ...	London.
DOVASTON, GEOFFRY EDWARD, . . .	London.
DOVASTON, WALTER AMYAS, . . .	London.
ELCE, NORMAN, ...	Southport.
ELLIS, CHARLES WILLIAM, . . .	Harrow.
ELY, RAYMOND EDWARD VICTOR, . .	Sutton, Surrey
FOULSHAM, FRANK CHESTER, . . .	Twickenham.
HALL, SIDNEY MORETON, ...	Middlewich.
HARMAN, ALBERT WILLIAM JOHN, . .	Windsor.
HARVEY, ALAN JANNINGS, ...	Fareham, Hants.
HOLMAN, CLIVE WHELPTON, . . .	London.
HOLMES, JOHN BERNARD, ...	London.
HOPKING, ALFRED GEORGE, . . .	London.
LEECH, JOHN, ...	Sunbury.
LORD, LEONARD PERCY, ...	Coventry.
MASTERS, ERIC RUFFLE, ...	London.
PINHEIRO, LUIZ MONTEIRO, . . .	London.
ROBBINS, BRIAN GORDON, ...	London.
STEBBING, REUEL CHARLES, . . .	Colchester.
STOREY, JOHN STANLEY, ...	Keighley.
THOMAS, WILLIAM ALEXANDER, . . .	Cardiff.
WALKER, IAN DRUMMOND, ...	London.
WEDDERBURN, DAVID WALTER, . . .	Southampton.

TRANSFERENCES.

The CHAIRMAN announced that the following twenty-seven Transferences had been made by the Council since the last General Meeting:—

Associate Members to Members.

ALLSOP, JOHN WILLIAM KIDSTON, . .	London.
BARBER, JOHN HARRY, ...	Sheffield.

Britton, Edwin John James, Lieut.-Col., D.S.O., R.A.O.C.,	London.
Clayton, Melville Graham,	London.
Connell, William Percival,	Bilbao.
Cook, Sydney Herbert,	Liverpool.
Greenshields, Charles David,	India.
Hargreaves, William,	Stockport.
Hoare, Arthur Richard,	London.
Hoare, Horace James,	Colombo.
Holliday, Thomas, Capt., R.A.O.C.,	Chatham.
Kennedy, Stuart Samuel, Lt.-Col., R.A.F.,	London.
Kidner, Alfred Egerton,	London.
Knox, Robert Graham, O.B.E.,	London.
McCarthy-Jones, Christopher Howel,	London.
Maggs, Charles James,	Demerara.
Martin, Francis,	Haywards Heath.
Nowell, Victor Ferdinand,	Calcutta.
Perkins, William John,	London.
Pitcairn, Francis Bernard,	Shanghai.
Roberts, William Poulter,	Madras.
Scaife, Joseph Dyson,	Newark-on-Trent.
Scoble, Walter Alfred, D.Sc.,	Woolwich.
Thomsen, Thomas Christian,	London.
Thornycroft, Sir John Edward, K.B.E.,	London.
Whitehouse, William Henry,	Letchworth.
Williams, Alfred Edward,	India.

Dr. Hopkinson's *Presidential Address* was then read by Mr. Michael Longridge (*Past-President*).

The Chairman announced that the next Meeting would be held on the 21st of November in their own Building. He was sure the members would desire again to express their great thanks to the Council and Members of The Institution of Civil Engineers for the accommodation which had been provided for them during the War. (A Vote of Thanks had already been accorded to The Institution of Civil Engineers at the last Meeting in May.*)

The resolution was carried with acclamation.

The Meeting terminated at Twenty minutes past Seven o'clock. The attendance was 188 Members and 82 Visitors.

* Proceedings, I.Mech.E., 1919, page 539.

ADDRESS BY THE PRESIDENT,

EDWARD HOPKINSON, Esq., D.Sc., M.P.

I.

To be President of The Institution of Mechanical Engineers is a great honour; it is also a great responsibility. Only those who have served as President can realize how multifarious and exacting are the duties which attach to the office, and how real is the responsibility which their adequate discharge entails.

It has been the custom hitherto for the President to deliver his Address soon after assuming office, and he has thus been enabled to take an early and fitting opportunity of expressing his appreciation of the honour conferred upon him. Circumstances this year made it desirable that my Address should be postponed from the March Meeting to this, the opening Meeting of the new winter Session. I have thus, before addressing you, been able to gain from my own experience of the last few months a fuller knowledge of the work of my predecessor, Mr. Longridge, who through two difficult years of war gave his time and ripe experience in unstinted measure to the service of the Institution. You will permit me, therefore, while thanking you for the honour conferred, to express my sense of diffidence in attempting to follow in the steps of my predecessor.

The Institution emerges from the war period with an increased membership in all grades except that of Graduates, though the normal rate of increase in members has not been maintained.

Since the conclusion of the war there has been a marked increase in the applications for membership, and there is every reason to anticipate rapid growth in the number of members in the immediate future.

It has been already announced that H.R.H. the Prince of Wales has consented to become an Honorary Life Member of the Institution, thus following King Edward and King George. The Council have also elected as Honorary Life Members Sir Richard Glazebrook, C.B., and Sir Rajendra Nath Mookerjee, K.C.I.E. Though Sir Richard Glazebrook would not claim to be a Mechanical Engineer, engineering owes a great debt to him for his work as Director of the National Physical Laboratory which he developed into an essential factor in the progress of Engineering science. Some of the most important Research Work undertaken by the Institution has been carried out at the National Physical Laboratory, more particularly the extensive Research on Alloys and that on Hardness Tests, which are still in progress. Many of our Members who undertook the manufacture of shell and fuses for the first time during the war will remember their despair at the impossibility of obtaining official test and approval of the necessary gauges until the work was undertaken by the National Physical Laboratory, which thereby removed a most serious hindrance to the production of munitions. We observe with satisfaction that by the appointment of Professor Petavel, a Member of the Institution succeeds to the post which Sir Richard Glazebrook has just relinquished.

It is also equally appropriate that at a time when the common prosecution of the war has brought the constituent parts of the Empire into closer relationship, the name of a distinguished Engineer, who is also an Indian subject of His Majesty, should be added for the first time to our Roll of Honorary Members. Sir Rajendra Mookerjee has rendered great service in the development of Engineering work in India, more particularly in connexion with light railways, pumping and storage plant for water supply and drainage, and the erection of public buildings and industrial works in the Province of Bengal, and also by the interest he has taken in Engineering education.

When, more than two years ago, my predecessor addressed you, he spoke in the very midst of the struggle, ever increasing in intensity to its sudden and dramatic conclusion on the signing of the Armistice. "The victory we all pray for," he said, "may be won before my successor takes my place." So it has been, and I address you nearly twelve months after the conclusion of hostilities and when peace, if not completely re-established, is so far secured and settled that the belligerent nations can turn from the problems of war to the not less difficult and serious problems of peace. Under such circumstances it can hardly be otherwise than that I should turn my thoughts to some of the effects of the war on the industry and profession whose interests it is the function of this Institution to conserve and promote, and to lessons war has taught us which must be marked and learnt, if we as a corporate body are adequately to discharge the duties of our calling. To quote again the words of Mr. Longridge: "The war has taught us many things, but none more clearly, more insistently than the importance of our Engineering Industry. Upon this industry we depend for victory to-day, and for security and prosperity to-morrow. Should it be wrested from us, as many industries have been during the past half century, England would fall to the rank of a second rate power and the British Empire would be dismembered. The war has made us realize the possibility of this great disaster and has brought home to us the need of action to avert it." Now, in the light of fuller knowledge and accomplished fact, we realize, and I believe the nation realizes, that our increasing supremacy in Mechanical Engineering, established as the war proceeded, was indeed an essential factor in victory. Do we and does the nation grasp with equal conviction that if that supremacy is impaired, we cannot hope to solve the problems of reconstruction? We are entering on a new decade which may well prove as difficult and critical as that we are leaving behind. We can achieve success only by years of patient and strenuous work, whose keynote must be the national unity of effort in war translated into our industrial life. Industry must be reorganized with methods, personnel and plant more efficient, more productive, and more perfectly adapted

to their purpose. As Mechanical Engineers, we ought to realize that both the direction and the execution of this reconstruction lie largely with us. It is fitting therefore that we should leave no stone unturned in seeking out and eliminating the causes of our past failures and in finding means whereby we can best satisfy the present and future industrial needs of the country. It is difficult to add anything new to the great mass of literature already existing on these matters. I shall not attempt to do so, and will refer only to certain subjects to which, from my own experience, I consider our attention may be directed with profit.

II.

Administration and Organization.—If we are to maintain, or perhaps I should say, if we are to prevent further encroachments upon our established position in the Engineering world, Mechanical Engineers must give more attention to the administration and organization of workshops. We have omitted to realize that to make an efficient machine is one thing, but to make it efficiently another thing. It is no exaggeration to say, for example, that the great majority of British Engineering works before the war were utterly unprepared to deal effectively with high-class repetition Engineering work. Except in the National Arsenal and a few other Engineering works, the system of working accurately to gauges with defined limits and tolerances to ensure interchangeability of parts was almost unknown before the war. Before the end of the war the National Physical Laboratory was testing 10,000 gauges per week.

The exigencies of war have taught us much and have, I think, brought to the fore a considerable number of young Engineers of natural administrative and organizing capacity. But administration and organization cannot be left entirely to natural aptitude, even when combined with long experience. There can be little doubt that in the future our shops must be managed by younger men, of more limited personal experience than has been customary hitherto, who will therefore need to rely to a greater extent upon

the experience of others, acquired through reading and lectures. These questions of management and organization are vital matters which ought not to be left to chance and should form part of the specific training of a Mechanical Engineer.

The full freedom of industries in availing themselves of the new mental material turned out by the Technical Schools and Colleges has been hampered by the innate conservative prejudices of the so-called practical man. The man from the Technical Schools, however brilliant, could not hope to obtain recognition as a useful member of the administrative staff until he had been through a mill of two or three years of what is designated practical training, during which he could earn no remuneration and might count himself fortunate if he was not called upon to pay a premium for the privilege of working. His heart was often broken by the drudgery of repetition work coming at a time of life when minds are most receptive and fullest of desire to be of use and to absorb new ideas. The war has changed the outlook of the Works Manager. He has begun to realize that the man who has the advantage of wide reading and of thorough technical training, provided he has a natural practical bent, may make a far better Under-Manager than the man who has not these advantages, but has spent a much longer time in the workshop. One reason which has militated against the more rapid absorption of the product of the technical schools as an integral part of workshop organization is to be found in the fact that too little time is given in the schools to teaching the art of production.

The right use of tools and the accommodation of design to the methods of manufacture and to the tools available receive too little attention. Many lectures are devoted to the design and working of a dynamo or steam-engine, but few to that of a lathe or milling-machine. How often are parts of scientifically correct design incapable of being moulded economically in the foundry or tooled economically in the shop?

Engineers have had an unhappy experience in this respect during the war through having to carry out Government designs, the product of the Drawing Office without regard to the Works,

designs unchastened by the necessity of having to hold their own in the world's markets. Yet, I do not believe that it is impossible to inculcate the basic principles of economical production in the class-room, the laboratory and the workshop of the Technical School as effectively as, and certainly in a much shorter time than, in the factory. If such subjects were widely taught, the student would soon discover in what direction lay his natural bent and would in his own mind specialize in that direction, and when he came to the workshop, would be able to show that he could readily absorb shop training in his own specialized subjects and make himself useful therein. If a man, soon after leaving College, can show that he is capable of occupying a definite post in workshop organization, it will qualify him to pass from one works to another and so to obtain experience of different conditions and methods, and, as is most desirable, in countries other than his own. Happily, the war has done much to break down the prejudice against interchange of experience in the Engineering industry, for, where almost all have been forced by circumstances to turn from work to which they were accustomed to other work of quite different character which had to be carried out under pressure of extreme urgency, Managers soon found out how much they could help each other, and in responding to the national need came to realize the advantages of co-operation.

Our Institution also has an important part to play in this respect. Much can be done by encouraging the reading of Papers which deal with workshop organization and with production from tools. There has been already a noticeable increase in Papers of this character, and I hope it will continue. I do not agree that the discussion of these problems will tend towards advertisement, lower the general scientific status of the Papers, or emphasize unduly the purely commercial aspect of works production. A description of the means adopted by a Works Manager to obtain maximum production of the required degree of accuracy at minimum cost is as important to the progress of Mechanical Engineering as the description of a new invention.

There is another side of Engineering at which it is too often the custom of Engineering Institutions to look askance,

namely, that concerned with the distribution and selling of the product. In most Industrial Engineering undertakings, the Commercial section of the staff is larger than the Designing, Testing, and Foreman Section, and it is just as essential to the highest success that it should be composed of trained Engineers. A very large proportion of the men who enter Engineering works with the intention of fulfilling their calling in constructive work find that they are drafted, through the force of circumstances, to the commercial side, and develop their careers in that direction. No salesman of high-class Engineering products can be altogether successful unless he has the Engineering instinct and has had a sound Engineering training. The successful Engineer-Salesman must be able to understand and enter into the wants of the purchaser and suggest means for satisfying them. He must also understand thoroughly the properties and capabilities of what he has to sell. It is a common though erroneous idea that a man ceases to be an Engineer when he becomes involved in the commercial side of Engineering. On the contrary, it often happens that in discharging his commercial duties he is using to the best advantage his Engineering knowledge and aptitude.

In a recent Paper read before the Institution of Electrical Engineers, entitled "The Functions of the Engineer, his Education and Training," Lieut.-Col. O'Meara discussed in great detail the extent to which teaching in the subjects of administration, organization, and commercial management "indispensable to the complete Engineer" should form part of the curriculum of Engineering education. His conclusions are based on the fact, too little recognized by those responsible for the conduct of our technical colleges, that in after life a far larger proportion of Engineering students find their vocation in the administrative rather than in the technical side of industry.

In Mechanical Engineering, perhaps more than in any other branch of technical science, the inventor, the designer, and the research worker must keep in constant touch with the workshop organization. This interdependence should be recognized throughout his college training. For the average man it may be necessary

to cut down the hours spent in higher technical work and devote the time so gained to administrative and commercial subjects, and for the exceptional man to postpone some of his higher technical work to a later part of his college career.

Whatever may be the steps taken to widen the curricula for Engineering students, it is essential that those occupied in administrative duties should recognize that successful administration is based on principles which are capable of definition and of scientific treatment and analysis, that the accumulated experience of others can be put into a form in which it can be taught and learned, and that those mental and moral characteristics which are essential in the good administrator can at least be developed if not implanted by training.

We must not, however, be content with teaching only those who are to administer our works and factories. We shall never get the best out of any system of organization or administration in any field of work unless the workers themselves understand the principles upon which the system is based. A wise Manager in an Engineering shop will make no changes without first explaining their object to the workers, probably through the medium of the Works Committee. A still wiser Manager will so develop the interest of the workers in efficient administration, that proposals for improvement originate with them, and they thus assume the position of having to prove their case. With this in view, it is most important that there should be evening classes in administrative subjects in our Technical Schools.

Largely due to the experience gained during the war, the need for systematic instruction in industrial administration has been so prominently forced on the attention of those responsible for the conduct of some Lancashire Engineering and other industries, that a year ago six firms combined to make an offer to the Manchester Municipal College of Technology to provide an annual sum for the establishment of a special Department for this purpose. The Department has been constituted and is worked in close co-operation with an Advisory Committee of those who are themselves engaged in works administration. A Director has been appointed with

three Assistants. The objects of the Department are stated in the prospectus to be:—

1. To study scientifically all questions regarding industrial management and to collect and co-ordinate the information obtained.

2. To use all knowledge gained with the object of furthering the education of managers, workers, and students.

3. To assist in building up a science of industrial administration, and as far as possible to work out its applications to all British Industries.

It is said that some 500 books have been published on scientific management of workshops and that 90 per cent. of these are American. There is thus no lack of literature on the subject, but there is great need for its digestion and consolidation into a form more readily useful to the student.

The material side is only one part of Works Administration; not less important is the purely human factor. All that pertains to the physical health and mental contentment of the workers is reflected in the efficiency of their work. We have, in many respects, paid far less attention to these matters than the Germans, the Swiss, or more particularly the Americans, but it is significant that the Director of the new Department of Administration in the Manchester College of Technology is a physiologist.

Comparatively little work has been done in England in the quantitative measurement of variations of productive power dependent upon the hygienic conditions of the workshop, and yet in many cases it is possible to establish a definite relation between them. Largely due to lessons taught by war conditions, it has become a recognized practice in well-organized works to appoint Welfare Superintendents and Apprentice Masters whose function is to promote healthy conditions of mind and body for the workers. Such officials can abundantly justify their position.

The most important problems in the human side of administration are those connected with Industrial Fatigue. The efficiency of a man as measured by his capacity for output is dependent upon his hours of work, both in length and distribution, and the integration of the curves connecting rate

of output with time of work will show the maximum amount of work which can be obtained from the individual. The investigation of these questions on a scientific basis is of a peculiarly difficult nature on account of the large number of independent variables which affect the result. It may be shown, for instance, that a workman's output is actually greater when working 48 hours a week than when working 53, but such a conclusion may be inapplicable generally because the greater capacity for work may be due not merely to the shorter hours, but to the fact that the shorter hours provide a better distribution of worktime and playtime. For example, the shorter hours may enable the before-breakfast hours of work to be completely abolished, and this may have salutary effects dependent upon quite other factors than length of working hours. Again, to arrive at results capable of wide application, observations must be made over long periods, the object being to ascertain the conditions necessary for the continued maintenance of human effort at its maximum efficiency.

Thus, observations limited in time might show that it would be better to add the hours of Saturday morning's work to the five other working days in the week and thus ensure two clear days, but more extended observation might show that instead of two days' freedom from work in the week, it was better to allow the hours of leisure to accumulate and ensure a month's complete holiday in the year. Another difficulty is the fact that as yet physiologists have not discovered any definite means of measuring fatigue or of determining the state of the body at any particular time with regard to fatigue. Many experiments and much observational work have been carried out with a view to finding such a measure, but with only limited success, and at present the only measure of capacity for work at a given time appears to be the actual rate at which work is done at that time. This is obviously unsatisfactory, because it introduces many factors other than the purely physiological ones of fatigue. It is, for example, a well-known fact that the maximum rate of work does not occur after relaxation. It takes time, as it were, for a man to get into his stride. These are probably psychological effects and

not purely physiological. Notwithstanding the difficulties which surround investigation, I am convinced that discussion of the deductions drawn from systematic observation by the physiologist and the psychologist, combined with the inductive conclusions of the works manager, will yield most valuable results. There is no doubt that if such investigations had been made some years ago, they would have led to a general shortening of the hours of labour, and the absurdly excessive hours worked during the early part of the war would never have been permitted, as it would have been understood at once that their only results would be the accomplishment of less work and the prejudiced health of the worker.

The appointment last year of the Industrial Fatigue Research Board by the Department of Scientific and Industrial Research and the Medical Research Committee jointly, at the request of the Home Secretary, shows the importance attached to a comprehensive and systematic investigation of these problems. It is the duty of the Board to "Consider and investigate the relations of the hours of labour and of other conditions of employment, including methods of work, to the production of fatigue, having regard both to industrial efficiency and to the preservation of health amongst workers." The Board has a considerable staff engaged on particular lines of inquiry and has already published several Reports.

The right and economical use of the human labour working a tool has given rise to another line of investigation in workshop administration known as "Time and Motion" study.

A "best" way can be found of performing any operation dependent upon muscular effort by methodical and scientific study of the various motions involved. For some concrete examples of the advantages to be derived from such investigations I would refer you to Report No. 3, published by the Industrial Fatigue Research Board, "A Study of Improved Methods in an Iron Foundry." Before beginning his investigations, the employer in this foundry took the workpeople into his confidence and explained his aims to them. He then analysed the different jobs into their various elemental units. Each movement was studied separately and

timed with a stop-watch. All superfluous movements were then eliminated, those which could be performed simultaneously were combined and the tools and material arranged accordingly. On this data he established standard sets of movements and times which were written down for the workmen to learn on cards pinned up over their machines. The application of these principles simultaneously with a reduction of hours and a system of payment involving a higher price per piece as production increased, effected in this particular workshop an enormous increase of output.

As a particular instance of the use of motion-study, I may mention the case of a man in the same workshop who for some reason could not keep up with the standard of other men working duplicate machines even although he was most anxious to do his best. It was eventually discovered that he was left-handed, and that evening, after the works were closed, a mechanic altered his machine into what was to all intents and purposes a left-handed machine and his tools were arranged for left-handed use. The next day he was on time all day although previously he had been 15 per cent. slow.

Though the actual application of such principles can only be carried out in the workshop and gauged by practice there, the importance of their study and the methods of studying them may well be taught at School or College.

Our Public Schools take infinite pains to teach boys how to get the most out of a cricket bat or an oar with a given amount of muscular effort; coaching in rowing or cricket is acknowledged to be essential; why should not our young Engineers have similar coaching in the multifarious manual operations of an engineering shop? The analogy of our organized school games also suggests that the interest of the worker may be enhanced and sustained if he is treated as a member of a team playing for a definite goal. "Team Work"—that is, the combination of individual effort to achieve a definite result—ought to be developed to a much greater extent than hitherto in our workshops, and must increase efficiency and improve discipline.

Attention has recently been drawn to another psychological

aspect of the labour question in engineering workshops where modern conditions are unfavourable to efficient work compared with those that obtained in earlier days. In the old days, a millwright employed, for instance, in the setting out of a main gear for driving a mill, himself drew it out on the drawing floor, received the wheels from the foundry and set them out for tooling, and finally was usually selected to erect and set to work. From beginning to end of his job he had a clear idea of the ultimate use to which his work would be put, and was largely responsible for it until put into operation.

Thus, he had a real interest in his work as such and must have derived mental satisfaction and encouragement from the results of work well done. An incentive to effort in addition to the mere earning of a wage was ever present in his mind and cannot but have contributed materially to his efficiency. Such incentives have necessarily disappeared under modern workshop conditions, where the workman knows but rarely what are the particular objects to which his work will be applied and what may be the ultimate effect of good or bad workmanship. The turning out of a certain quantity of work which will pass inspection limits his mental horizon and must of necessity induce staleness, lack of interest, and mental fatigue. Probably much may be done, even under the stifling conditions of modern repetition work, to impart to the workman a fuller knowledge of the ultimate object of his labour and so to engender a keener interest therein.

It was customary in many workshops during the war to post in prominent places the output of the shop from day to day, and undoubtedly the practice had a most salutary and stimulating influence, but will that war lesson be carried forward into times of peace?

III.

Production.—In the foregoing remarks I have tried to indicate a few of the causes which have contributed to arrest industrial development and to point out some of the means which will help us to regain what we have lost. All have one end in view; to

increase our production by greater efficiency in the administration of industry and in the application of labour and by avoidance of waste, whether of raw material, physical energy, or human effort. They are based on the assumption that there is a will to work and a desire on the part of the worker to expend his labour to the best advantage. If these are absent, or cannot be engendered, labour itself is vain, and all efforts to improve its conditions doomed to failure.

Though the more far-sighted leaders of public opinion both among employers and employed now realize that only by increased production can we recover from the losses and damage of war, recent events too clearly prove that this truth has not yet permeated all classes of the nation. It has been thrust into the background by the demand for the establishment of a higher plane of living for the working classes without consideration of the means whereby it can be obtained. It would be unsuitable for me to discuss here this demand in its ethical and social and still less in its political aspects, but we as Engineers would do well to realize that the problem has to be solved and that the solution rests largely with us. Unfortunately the real issue has been obscured by diversion of attention from the elementary physical facts to consideration of economic theories which lead into many side-tracks and involve side-issues which only serve to distract the mind from the fundamental facts. The working classes of this country must be better fed, better clothed, better housed and be able to enjoy the amenities of life in fuller measure than in the past; they must have more time for recreation of mind and body and ampler means for promoting physical and intellectual welfare. Surely it would appear obvious that these conditions can only be fulfilled by an increase in the productive power of English industries. This increase in productive power is, *ex hypothesi*, not to be obtained by longer hours of work, but is to be accompanied by shorter hours. Yet Labour has shown itself averse to the tapping of fresh sources of supply by allowing the lower grades of labour to undertake higher and more productive grades of work and by the increased introduction of female labour, not perhaps to

the extent that was possible and necessary during war, but to a far greater extent than in pre-war days. War conditions have amply demonstrated with what success both can be accomplished. For myself, I believe the increased production necessary in many industries cannot be attained under the conditions postulated without a change in the application of labour and an increase in the number of those employed. For it must be remembered that increase in production must be far greater than is necessary to meet merely the added home consumption, for, as a country, we produce only a fraction of the raw material we require for our own sustenance and the feeding of our industries, and the deficit must be made up out of imports which we pay for out of our manufactured products.

Thus, it follows that every step in increasing consumption can only be achieved by increasing production in a much larger ratio. It is too often popularly assumed that the higher remuneration of Labour will by itself secure an industrial Utopia, and that Labour, if it has more to spend, will be able to satisfy its desires. Experience has shown that the very contrary is the fact. Mere increase in wages, mere changes in the distribution of wealth, have the effect in themselves, divorced from other influences, of providing less rather than more of the good things of the earth. It has been proved again and again from actual figures of most of our staple industries that a re-distribution of the profits of industry, however desirable on other grounds, cannot in itself materially add to the welfare of Labour unless it directly conduces to increased production.

If, as a nation, we are to realize what we all desire, a fuller and happier life for all classes of Labour, every proposal for increase or change in the methods of remuneration of Labour, every proposal for sharing or re-distribution of profits, every proposal for change in control or in the management of industry ought to be subjected before adoption to crucial examination as to whether it will increase production per worker or can be accompanied by other changes in the conduct of the industry which will in their combined effect achieve the same object. Unless they satisfy this test we shall fail in attaining our

end. Instead of promoting the welfare of the industry and of those engaged in it, we shall doom it to decay and ultimate extinction. I do not state the problem in this way in any spirit of pessimism. It is rather the reverse—because I believe it can be successfully solved and that its solution lies largely with the Mechanical Engineer, provided free play is given to his efforts and that sufficient capital is placed at the disposal of the industry. The application of the forces of nature to the benefit of man, the avoidance of waste, the efficient use of physical and human energy, the replacement wherever possible of human effort by mechanical contrivance are his particular sphere, and it is by these things that our material prosperity in the future will be assured.

IV.

India.—I have spoken hitherto solely of the home point of view with regard to reconstruction rather than of those wider considerations which apply to the Empire as a whole. In conclusion, I ask your attention for a few moments in connexion with some matters which vitally concern us as Engineers in one constituent part of that Empire—India, where the problems to be solved are not, as at home, those of reconstruction, but rather of construction.

Until a few years ago, India looked almost entirely to Great Britain for the bulk of her Engineering requirements. Her developing industries, the manufacture of coarse cotton goods and of the coarser qualities of jute goods, the getting of coal from shallow and easily worked mines, oil-drilling and refining, gold mines, the milling of rice and flour, together with the requirements of a few minor industries such as sugar, oil-pressing and saw mills, and lastly, but most important of all, her transport system, were all dependent for the continuity of their operation on the supply of products from the Engineering Works of Great Britain, and this dependence increased as the development of the industries into their higher stages required machinery of more advanced types. The Engineering world of India, however, is now entering upon a

new phase, partly in response to the insistent national cry for the better use of the natural resources of the country, and partly because, during the war, India ran serious risk of being largely cut off from communication with Great Britain and has learnt that it is essential in her own interests and in those of the Empire that she should be more self-contained industrially.

We may expect, therefore, that in the near future India will be in a position to rely less upon home Engineering products, and will supply at least the simpler forms of these products from her own resources. I am not concerned now to inquire in detail whether this tendency will have a good or bad effect upon British Engineering, but I may remark in passing that all industrial history shows that although there may be hardships in certain industries in the process, the industrial development of one country, closely knit in its commercial relations with another, is to the ultimate benefit of both. In India, this is especially true, because her engineering products must be applied chiefly to the improvement of transport and agriculture, and the winning and merchanting of various kinds of raw materials. Thus, the immediate effect will be to increase the export of agricultural produce and of raw materials, and as a necessary corollary to increase imports, for the greater purchasing power of the community engenders new wants of a higher character which cannot be satisfied by the indigenous industries of the country. To promote the development of Engineering industries in India is not generally in opposition to the best permanent interests of such industries at home, though it may entail temporary dislocation.

India has already laid the basis of an Engineering industry in the establishment of two important and successful Iron and Steel Works. The Bengal Iron and Steel Works under their present management have been established for some twenty-five years at Kulti, and have had a chequered career, during which, in 1903, an attempt was made to manufacture steel which proved unsuccessful and was abandoned. The Works are now most successful, both financially and in quality of product, turning out 10,000 tons of pig iron per month, about one-third of which is used in their own

foundry for the manufacture of pipes, columns and pot-sleepers and chairs. More recently, the Tata Iron and Steel Works have been erected at Sakchi on the Bengal–Nagpur Railway, about 155 miles from Calcutta, and in reasonably close proximity to their supply of coal and iron ore. The Works were started in 1912 and have two large blast-furnaces in operation, each capable of producing about 350 tons of pig per day, a third nearing completion, and three more much larger in process of construction. Most of the pig is converted into steel. The rolling mills produce about 120,000 tons of rails and smaller sections yearly. About 13,000 men are employed in the works, adjacent to which a town having 50,000 inhabitants has sprung up, carefully planned in every detail with suitable houses, mostly provided with gardens, for all classes of employees, and schools, institutes, and hospital. These two Works, even when extended, will not provide more than a fraction of the iron and steel India needs, of which the imports in 1913–14 amounted to over 1,250,000 tons.

At the present time, India cannot roll a steel plate nor draw a steel tube; there are no rolling mills for tinplate, or for copper or brass sheets. Lead-piping, galvanized sheets, steel wire, copper and brass rods are not made in India, and no steel castings are produced except on a limited scale at some of the Ordnance Factories and in a few of the Railway Works. Even railway axles, carriage springs, wire ropes and chains are imported. No steam-engines of any size are constructed, probably the largest are those of some 400 h.p. for river craft. Portable engines, traction engines and road rollers also are not made, nor steam-boilers, except a few of very small capacity. Agricultural machinery, the greatest need of all in India, is not manufactured except to a limited extent in its simpler forms. Substantially no cotton or jute machinery, either for spinning or weaving, is made in the country. Locomotives cannot be built without obtaining many essentials from abroad, and ship-building is in its most elementary stage. Electrical machinery of every kind is imported. Apart from the Railway workshops, the principal centre of general Engineering workshops in India is Calcutta,

but in 1915 there were only 27 of these with an aggregate of 12,000 employees.

Owing to the pressure of war conditions, the situation in respect of Engineering industries is rapidly changing. The Tata Iron and Steel Company will shortly have a large plate mill at work for rolling plates up to $1\frac{1}{4}$ inch thick, and it is proposed to construct a wire mill and a bolt and nut shop of large capacity. Works are to be erected for the manufacture of tea machinery, which hitherto has been entirely imported. Schemes are in hand for the manufacture of agricultural implements in India from Indian steel. Vacuum brake material, as required by the Indian railways, is now being made in India. Galvanizing is being carried on on a fairly large scale by several companies. A large workshop has been erected for the manufacture of jute mill machinery of all classes, now entirely imported into India. Such are only a few of many instances of advance.

During the war we have, perhaps unavoidably, lost much ground both professionally and industrially in India. The higher management of the Tata Iron and Steel Works is in American hands and much of the plant is of American origin. The same is largely true of the hydro-electric developments in the Province of Bombay. What I have described with particular reference to Engineering industries might be applied with equal truth to many other industries which will develop in the next few decades and which will, each one of them, be dependent upon expert engineering knowledge. I mention these facts, because I wish to draw the attention of our younger members to the field which India must shortly offer for employment to those who are capable of initiating and directing new industries. India, whose wealth has increased greatly during the war, does not need to rely in the future as in the past upon British capital, but she must rely for many years to come on British brains and expert knowledge. Every step in the process of development will be accompanied by a more intelligent and increased demand for mechanical plant for application to indigenous industries and particularly to agriculture, which must always remain by far the most important.

Let me quote some figures taken from the Report of the Industrial Commission, which illustrate strikingly the need for greatly increased application of machinery. In British India there are 210,000,000 acres under cultivation and in 1911 80,000,000 people were employed on the land; one person to every 2·6 acres. The corresponding figures for Great Britain and Germany were one to 17·3 and one to 5·4 acres respectively. The respective standards of yield of wheat and barley in England and India are 1919 lb. and 814 lb. per acre for wheat and 1,645 lb. and 877 lb. per acre for barley. The explanation of such facts largely lies in the neglect of the application of machinery to agriculture, both in the field and in the processes of preparation of agricultural products. The value of agricultural machinery imported into India in 1913–14 was only about £18,000, and yet India stands third in the wheat and barley producing countries of the world. India produces 3,000,000 tons of raw sugar per year, yet the value of sugar machinery imported is only about £30,000 a year, whereas she imports £10,000,000 worth of manufactured sugar.

It is estimated that there are more than 3,000,000 irrigation wells in India worked by men or cattle and not much more than 1,000 worked by mechanical methods, although the use of the latter in Southern India has shown that small power pumping plant units, either steam, oil, gas or petrol driven, can be most advantageously employed.

It is important for the profession and for industry to note the changing attitude of the Government of India and of the Home Government in regard to the purchase by the former of the material required for Government undertakings. Before the year 1913, the rules of the Government of India for the instruction of Purchasing Officers empowered to buy stores narrowly restricted purchase in the country itself and required the sending of indents home that purchase might be effected through the Stores Department of the India Office. In 1913, the rules were revised and have been subsequently further modified with the object of giving wider powers to Purchasing Officers to place orders with Engineering

firms established in India, whether as manufacturers or as suppliers of Engineering material. These altered rules appear by no means to have attained the object which the Government had in view, and, whether in order to divest himself of responsibility, or doubtful of his own knowledge of the material to be ordered, the Purchasing Officer continued to send indents home for stores which might have been purchased in India. The creation of an organization for the purchase and inspection of stores in India is now proposed, so that all indents for Government and railway stores may be met as far as practicable in India. If the proposals are carried into effect it must necessitate, on the one hand, a larger number of Mechanical Engineers resident in India in association with engineering firms already manufacturing there or importing from home, and on the other hand, the setting up of a competent advising and inspecting engineering staff attached to the Government of India to carry out work which is now largely done in England.

The Industrial Commission, in considering the means they can recommend to the Government whereby it can give direct encouragement to Industrial development, have been led to make recommendations of a far-reaching character, some of which are of particular interest to the Engineer. I may quote some of these proposals in as condensed a form as possible. Various Departments of the Government of India and of the Provincial Governments such as Forestry, Agriculture, and the Geological Survey have on their staff a limited number of scientific officers, each devoting himself to the solution of particular problems which may arise in his Department, but forming no part of an organized Service and so deprived of the advantages of the prestige, *esprit de corps*, security of merited promotion and means of intellectual intercourse which attach to a Government Service. Among these scientific and technical officers are men of the highest scientific attainments whose researches have already resulted in immense benefit to the country, but their numbers are totally inadequate compared to the importance and the number and complexity of the problems to be solved. In Forestry, the work of the Conservators and the

scientific investigations of the Botanist and Mycologist do not bear their full fruit because there is no corps of trained Forest Engineers to solve the problems of extraction, transport, and preparation of timber for the consumer. There are individual Chemists employed in many of the Government Departments, but there is no bond of union between them, and the industrialist desiring the assistance of Government in a chemical problem has no means of obtaining authoritative advice. It is difficult for us in this country, with all the advantages we possess of consultants in engineering, in chemistry and other scientific branches of industry, with Research Laboratories at our Universities and in some Government departments, to realize how great is the setback to industrial development when these are non-existent. But even we, with our long established advantages, are beginning to appreciate the fact that the application of science to industry must have unlimited scope and are supplementing national institutions for research by private institutions in individual works or in associations of industries. Yet, in India, industrially an undeveloped country and with a different range of natural resources, the need is as great, and there is practically no present means of satisfying it.

The Report advocates a reorganization of the existing scientific Services so as to unite into one Imperial Service, classified according to science subjects, all the scattered workers now engaged in the Provinces on isolated tasks, a large increase in personnel and the establishment of an Imperial Chemical Service. The advice of the members of these Services would be available for the benefit of private industrialists under suitable regulations. The head-quarters or home of the Services would be in the research institutions already established or to be established in connexion with the different branches of the Services which would, as it were, form the reservoirs upon which Local Governments or private interests could draw for scientific officers or advice.

The direction and co-ordination of the general industrial policy of the country is to be effected through an Imperial Department of Industries in charge of a Member of the Viceroy's Executive Council assisted by a Board of three members, each with a separate

group of charges. All three groups will involve the appointment of Engineering Officers for the discharge of their functions. Thus, if these recommendations are adopted, there will be set up in India an Imperial Service Corps of Mechanical Engineers. Officers of such a Service will no doubt be ultimately largely recruited in India, but, in the first instance, home sources of supply must be drawn upon, and it is well that it should be so, as the mechanical bent of mind is entirely foreign to the Indian and little has been done to develop it by education, either in its more elementary or more advanced stages. It still remains to be proved whether that desire to know and weigh things as they are, stripped of imaginative setting, and to use and handle tools, which are distinguishing features of the mechanical engineer, will ever take root in the Indian character.

There is as yet no base on which to build elementary mechanical training for the Indian artisan. With a people almost wholly illiterate, schools for the teaching of elementary mechanical subjects are useless for the ordinary boy, and in those that have been started it is soon found that the first years must be spent in imparting sufficient elementary education to enable the scholar to derive any advantage at all from vocational teaching. We must look to the workshop itself, not only for training in the particular crafts, but also for such general elementary education and rudimentary technical education as are necessary for the acquisition of craftsmanship. Although a man may become exquisitely skilled in the art of, say, carving ivory, or engraving brass, and remain entirely illiterate, depending upon hereditary genius in his craft, he cannot become a pattern maker or fitter unless he can read and understand a drawing. Wherever schools in direct connexion with workshops have been set up, the results have been most satisfactory. If a class of artisan mechanics is to be built up in India, every engineering works, either alone, if of sufficient size, or otherwise grouped with neighbouring works, should provide a school for teaching the boys employed both general subjects and also such elementary technology as is suited to the trade they are learning, and the teachers as far as possible

should be drawn from the foremen and others engaged in the works. The great railway shops and such other mechanical works as exist in India draw their foreman staff almost entirely from external sources, yet there is considerable material amongst the sons of existing foremen, amongst Anglo-Indians and to some extent amongst Indians themselves, which, with suitable training, might be developed into a useful source of supply within the country itself. The preliminary training of such material at junior Technical Schools involves many difficulties. Here, again, the only practical solution appears to be in the establishment of technical classes in direct connexion with the workshop, and to make attendance at these classes an essential condition of apprenticeship. Such a system is now under consideration by the East Indian Railway Company in connexion with their shops at Jamalpur.

These engineering developments in India must have a marked effect on the professional status of Engineers employed in India which it is incumbent on us as Members of the Institution to watch closely and, where possible, to influence for the benefit of our own Members in India and for the maintenance of high professional standards.

At the present time there are in India about 600 members of the Inst. C.E., 400 members of the Inst. Mech. E., and about the same number of members of the I.E.E., besides members of various other bodies such as the Inst. Naval Architects, the Iron and Steel Institute, and various Mining Societies. There are also, undoubtedly, many qualified Engineers in India holding positions of responsibility who are not members of a home Society. But India is a vast country, and these Engineers are split up into little groups working in places separated by great distances and only aggregated to any extent in such industrial centres as Calcutta and Bombay.

Such conditions make anything like corporate life very difficult and deprive the profession of those facilities for mutual intercourse, mutual exchange of experience and access to libraries which have such a large influence on members of the profession living under the more favourable conditions of this country. Efforts have been

made in various directions to overcome these disadvantages. The Engineers in the Public Works Department have formed Congresses in various centres. The Members of the Institution of Civil Engineers have attempted to start a branch of their Institution in India. Members of the I.E.E. have more than once endeavoured, but with small success, to maintain a local section of their own. Our own Institution has had a Calcutta and District Section since 1910, but it cannot be said to have had an active life, nor to have survived the adverse influences of war. There is a strong and growing feeling amongst our own Members that steps should be taken to minimize these disadvantages and develop more corporate life. The Members of the Public Works Department Congresses have realized that exclusion of all except Government Engineers, which was their policy until recently, was a mistake, and are taking steps to widen their constitutions. Further, it was realized that the Government of India might on many occasions derive advantage if there were a recognized corporate body, representative of the Engineering profession, which might be consulted upon such subjects as the education and training of Engineers, the grants of concession for mining rights or water power, the regulation of Electrical Supply undertakings, the certification of boiler attendants and similar matters.

The Indian Industrial Commission gave much attention to the various suggestions made to them by Engineers in various parts of the country on this subject, and in its Report advocated the foundation of a representative Society of Indian Engineers. It is obvious that conditions in India preclude the formation of individual institutions to represent the various branches of Engineering, and that the objects of such a Society could only be attained by combining all branches of Engineering, whether Civil, Mechanical, Electrical, Mining or R.E. The recommendations of the Commission have been actively taken up by Engineers of all classes, and I am glad to say especially by our own Members in India. The formation of such a Society was decided on at a representative Meeting held in Calcutta in December last under the Presidency of Sir Thomas Holland. A Committee was

appointed to draft proposals for the Constitution of the Society and Rules for its conduct and to consult all the various interests involved. I am informed that all the existing organizations have decided to co-operate in the formation of the new Society so that it will embrace and be representative of all professional Engineering interests in India. One proposed feature of the Constitution of the Society is of special interest to us as distinguishing it from our home Institutions. There will be a number of branches in such industrial centres as can support them which will be separate entities, largely governing themselves and providing for their own maintenance and the facilities they require, but subordinate to the central Council, which is to be located at Calcutta. It is proposed that the same subscription shall be paid to the central Council by all Members. The income from these subscriptions, after providing for the general expenses of the Society, will be available for grants to the local Associations. The determination as to the qualification of candidates for admission to the Society will lie entirely with the central Council, on whom therefore will rest the onus of maintaining a high standard of technical and professional qualification. The Council of our Institution has had a copy of the proposed Rules sent to it with a request for comments and advice thereon, and the Committee of the Council set up to consider it have reported that it is the apparent intention to maintain a standard of qualification for membership not less stringent than in our own Institution. It was at one time thought possible for the new Society to be formed under the auspices of our leading home Institutions, but for various reasons such a plan was not feasible, and I think it is generally conceded both here and in India that it is better that the Indian Society, knowing the wants of its own members and the local conditions, should devise its own constitution independently. At the same time, it is, I think, incumbent upon our Institution to use its influence in maintaining a high qualification for membership in the Indian Society and to collaborate with it with a view to obtaining the benefits for our own members in India, which such a Society can provide.

Vote of Thanks.

Dr. William H. Maw (Past-President) said that, as the Senior Past-President, he again had the privilege of proposing a vote of thanks to the President for the Address which had just been delivered. It was a matter of very deep regret to the members that Dr. Hopkinson was not able to be present, but he was sure they appreciated—as the President also would appreciate—the admirable manner in which the Address had been read by Mr. Longridge.

There were three outstanding points in the Address: (1) The importance of Works Organization on broad and thoroughly modern lines; (2) the desirability of paying attention to Motion Study; and (3) the possibilities of our Indian Empire. The President had given the members very valuable advice with regard to the first point, and coming as it did from a man who had been a most successful manager himself, and who had for many years studied works management, he was sure that his remarks would receive great attention and be very deeply appreciated.

With regard to motion study, he thought it was to be regretted that in this country the important hints to be obtained by motion study had not been so thoroughly attended to as they ought to have been. Motion study was making progress in this country but very slowly, possibly due to the fact that there were a comparatively small number of men who were able thoroughly to apply it. He was glad to hear that the training of men who were capable of applying motion study in a really practical way was going on steadily. Partially as a result of the War, the application of motion study to the training of men who had been disabled had been undertaken. In many cases it had been most important to ascertain how a man who had not the full use of his limbs could carry out certain operations successfully with a reasonable rapidity, and the motion study apparatus had on many occasions enabled men to do work which they otherwise could not have done without a very much longer period of training.

(Dr. William H. Maw.)

With regard to India, the members would remember that the President had for many years had exceptional experience in connexion with the development of India and had made a very careful study of its possibilities, and for that reason the statements made in the Address were worthy of very careful attention. He did not think it was necessary for him to make a longer speech, and he therefore formally proposed a very hearty vote of thanks to Dr. Hopkinson for his instructive and interesting Address, coupled with their most earnest wishes for his speedy and thorough recovery from his present illness.

Dr. W. Cawthorne Unwin (Past-President) said it afforded him very great pleasure to second the vote of thanks which had been moved by Dr. Maw. It would not become him to criticize in any way so valuable an Address based on such a very large experience of the subjects with which it dealt. The broad aspect of the Address showed that there was being extended to works administration and to workshop operations the scientific methods of study which had done so much for the country in other directions, and it was becoming clear that careful scientific study was just as much wanted in the workshop as in the laboratory. He had very much pleasure indeed in seconding the vote of thanks and in expressing what he was sure all the members felt—their regret that the President had been unable to be present and their hope that a period of rest would restore him to his full activities.

The Resolution of thanks was then put and carried by acclamation.

The Institution of Mechanical Engineers.

PROCEEDINGS.

November 1919.

An Ordinary General Meeting was held at The Institution, London, on Friday, 21st November 1919, at Six o'clock p.m.; Mark Robinson, Esq., *Vice-President*, in the Chair.

The Chairman said that, as the Senior Vice-President present, it was his duty to represent the President, who, he was sure the members would regret to hear, was seriously ill and unable to leave his house.

He was sure the members would wish to congratulate themselves on being back in their own home. The satisfaction they must all feel in returning to their own Building, he was sure, was very real. Even now a part of the building was still not ready for occupation, and there had been inevitable delay over the necessary reparations. Neither the Library nor the Reading Room was quite in order yet, but they would be available soon.

The Minutes of the previous Meeting, held on 24th October, were confirmed and signed.

The Chairman announced that the following six Transferences had been made by the Council :—

Associate Members to Members.

Barlow, Charles Robert, . . .	Cape Town.
Bharucha, Fakirjee Eduljee, . .	Poona.
Galloway, John, ...	Tayport, Fife.
Gill, Harold, ...	Singapore.
Panton, William Dickson, . . .	Calcutta.
Roscoe, Edwin Borton, Lieut., R.A.F., .	London.

The following Paper was read and discussed:—

"The Present Position of Mechanical Road Traction"; by C. G. Conradi, of Derby, *Member*.

The Meeting terminated at Twenty Minutes to Eight o'clock. The attendance was 180 Members and 77 Visitors.

The Paper by Mr. Conradi was also discussed at:—

Manchester, in the Engineers' Club, on Thursday, 27th November; Mr. Daniel Adamson, *Member of Council*, in the Chair.

Sheffield, in the Mappin Hall of the University, on Friday, 28th November; Professor William Ripper, C.H., D.Eng., D.Sc., *Member*, in the Chair.

THE PRESENT POSITION OF MECHANICAL ROAD TRACTION.

By C. G. CONRADI, of Derby, *Member*.

Transport of all kinds has become of such overwhelming importance to all members of the community, both individually and collectively as affecting the welfare of the Empire, that no apology need be made for bringing the question of mechanical road traction under general review at the present time. All branches of inland transport, namely, railways, roads, and waterways, are necessary to our national life, especially as regards the goods traffic and more particularly as regards the handling of the goods, apart altogether from the mere haulage of the same from point to point. The actual application of the power to the trains or vehicles on railways and roads is performed more or less in an efficient manner, and further progress is continually being made, if only slowly; but the methods employed for handling and carrying the goods are in most cases exceedingly crude, very few serious attempts having been made to employ the apparatus already available or to evolve new methods and machines for the saving of time and labour.

Comparisons between haulage by canal, rail, or road are frequently made nowadays, but surely the correct conclusion is that

each has its sphere of usefulness, and efforts should be made rather to control the whole so as to prevent overlapping and consequent waste. The roads, with which we are particularly concerned at the moment, would naturally, one would expect, act as feeders to the other two systems, and it is also on the roads that short-distance traffic would be carried. Where full loads can be obtained, the road vehicle working direct from door to door, with the consequent elimination of handling, is bound to score heavily over the railways on the shorter hauls, and under certain circumstances even on long hauls. A regular service, for instance, already exists between Nottingham and London, Birmingham and London, and between Lancashire and Yorkshire towns, whilst various Chambers of Commerce have formulated schemes for the co-operative handling of the traffic of their members by means of road transport. One of the great difficulties in the way of the economical operation of this traffic is the obtaining of full loads in both directions, and the constitution of freight exchanges becomes a necessity. A successful pioneer is that established by the Manchester Chamber of Commerce, which it is understood is now operated as a private concern, and similar bureaux should be set up in all the large centres with a view not only to providing a means of exchange between owners and users of vehicles, but of regularizing the charges and co-ordinating the work of all such centres. It is probable that such an organization would best be carried out by the Ministry of Ways and Communications.

Road haulage contractors are, however, soon involved in the same difficulties as the railway companies when miscellaneous traffic is to be dealt with, as terminals with large collecting and sorting accommodation have to be provided. Proposals such as have been put forward by Gattie for collecting and delivering miscellaneous parcels and goods traffic have much to commend them theoretically, but, although they do not present any difficulties on the engineering side, they appear to require further consideration from the commercial and operating point of view before any hope can be entertained of practical success.

There are two elements which constitute the system of road

traction, namely, the roads and the vehicles which operate upon them. The former do not enter directly into the province of the mechanical engineer, and it is not proposed to deal with them here; but it may be noted in passing that the condition of the road surfaces affects very largely the economical operation of the vehicles, and therefore becomes a highly important factor in the national economy.

Engineers who have been dealing with the maintenance of motor-vehicles during the last few years know how the increasingly bad condition of our roads and streets has swelled the total of failures and brought the repairs costs and time-out-of-service up to abnormal dimensions.

The report of the Departmental Committee appointed by the President of the Local Government Board to consider the question of motor road traffic goes to show that not only has motor traffic undoubtedly done damage to the roads, but also that the roads are largely unsuited to withstand the wear and tear to which they are now subjected by this class of traffic, the obvious conclusion being that road engineering has not kept pace with the requirements of the times. It has also been shown that the damage done to the roads, excepting the case of those of water-bound macadam, was mostly due to the iron and steel tyred traffic, which points to the necessity of equipping our vehicles as far as possible with some form of resilient wheel or tyre. The above-mentioned report gives certain information and recommendations as to speeds, axle weights, wheel dimensions, etc., and those interested may obtain copies from H.M. Stationery Office.

Animal Traction.—It is obvious that animal traction has a very limited field, and, on account of the low speed and small mileage possible per day, it must be confined to short hauls; although, on the other hand, its low first cost makes it difficult of replacement by mechanical haulage for certain classes of frequent-stop delivery work. When all expenses have been duly charged against animal traction, or, as we know it, horse traction, it has been found that in practically all spheres of operation it is more expensive and less

efficient than motor traction, its best relative performance being as indicated above in very short haul traffic with numerous stops, a service which is suitable to its low speed and radius of action. This can be readily understood, as the capital costs in the case of a horse and its comparatively inexpensive vehicle are low, whilst the repairs item is almost non-existent. Edison is reported as having characterized the horse as the poorest motor ever built, and credits it with an efficiency of 2 per cent., whilst the Author finds that a heavy railway dray horse has an average thermal efficiency of slightly over $1\frac{1}{4}$ per cent. The displacement of horses, however, by motors should not be undertaken too lightly nor without a full investigation of each case and the proper appreciation of the necessity for the operation of motor transport on scientific lines, so as to ensure economic success.

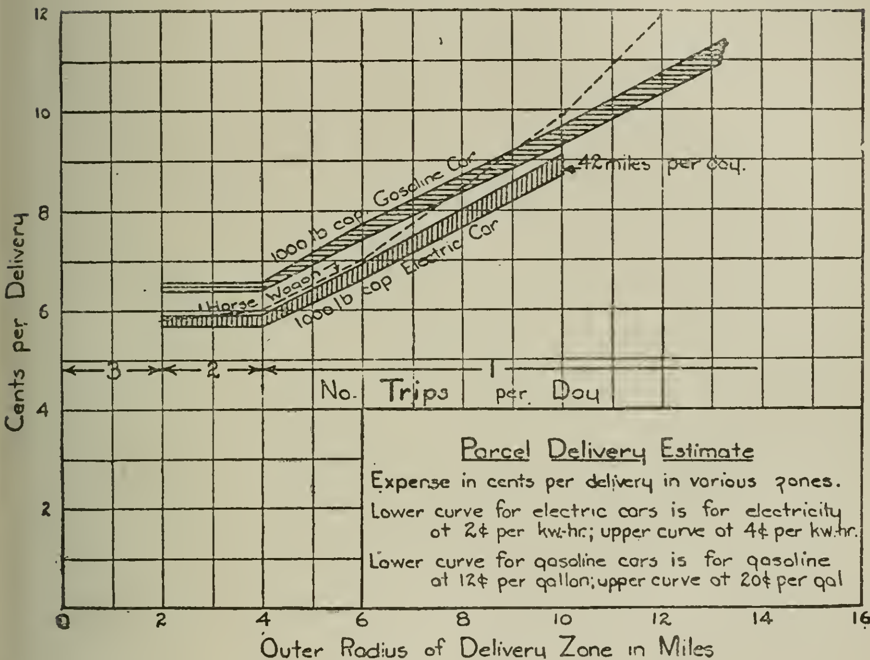
Much of the traffic congestion in our large towns is due to the slow-moving horse, and the only practical means of speeding-up the bulk is to eliminate the horse altogether from the most congested areas. This would no doubt come about automatically in course of time, but meanwhile the waste of time and energy continues. Slow-moving traffic might be prohibited from using the most badly congested streets during certain periods of the day, and the stream might with very great advantage be made uniflow in the narrowest ones, as has been done in the case of tramways in some towns, and also at the Front during the war, whilst the construction of subways to take care of cross streams would materially assist matters.

The present situation could also be considerably eased if traders could be persuaded to arrange to accept goods earlier in the morning, but it is recognized that they have substantial reasons for objecting to do so.

One frequently hears it stated that motors cannot compete with horses on short hauls, but this is not the fault of the motor so much as the method of application. The motor-truck is a time-saver; it will carry the same or a greater load much more quickly than horses, but *it is only a time-saver when moving*. Hundreds of motor-vehicles are not moving for as great a proportion of their time in commission as they should, and are therefore not as economical as

they might be.* The diagrams shown in Figs. 1 and 2 have been taken from a report on road transport issued some time ago by The Massachusetts Institute of Technology, and are based on 100,000 individual observations and owners' records during a period of 4 years. The width of the cross-hatched areas for electric and petrol

Fig. 1.



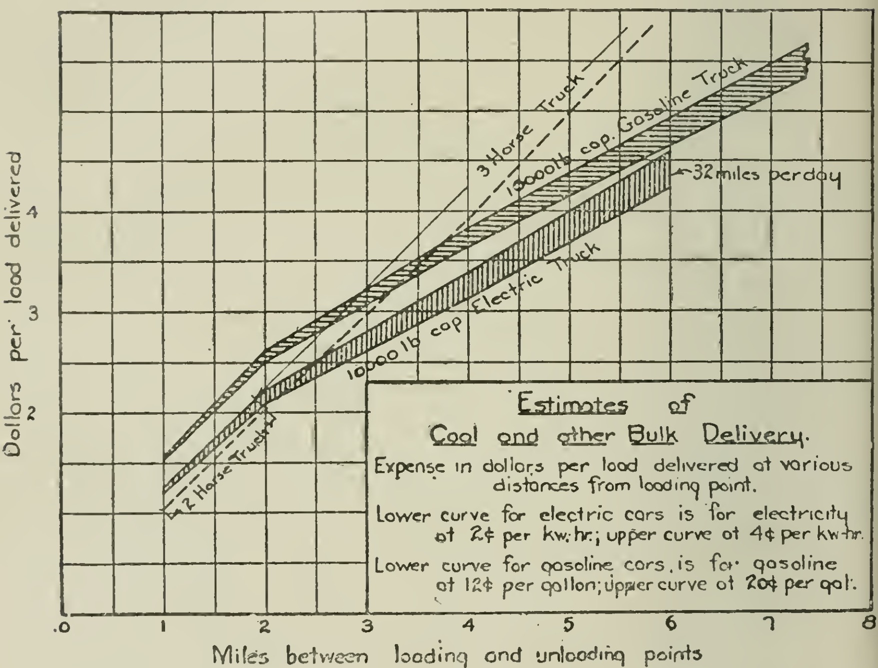
motors shows the effect upon total expense of variations in the charges for electricity from two to four cents per unit (1*d.* to 2*d.* = 100 per cent. variation) and in the cost of petrol from 12 to 20 cents per gallon (6*d.* to 10*d.* = 70 per cent variation). Actual money results must now be modified, but the Author's experience goes to show that the relative positions of the curves have not materially

* L. Brookman, "Self Propelled Electric Vehicles." Trans. Institution of Engineers and Shipbuilders in Scotland, January 1917.

altered except by way of improving the position of "The Electric." It will be observed from these curves that the horse is shown to have a slight advantage over even the electric vehicle on the heavier work within a radius of 2 miles, but better methods of operation can reverse this position in the majority of cases.

Time lost in loading and unloading is responsible in almost all

FIG. 2.



cases for motor inefficiency and for the fact that in some instances the cost per unit delivered is greater than with horses. Great waste takes place annually because users have not installed modern time-saving devices in connexion with their motor service, and it should be recognized that motor-traction cannot be made a commercial success if it is still to be operated on horse-pace methods. In too many cases the same methods of loading and unloading as

obtained with horse-haulage are continued when a change to motor-haulage is made, no cognisance being taken of the fact that the high standing charges of the motor are still going on whilst it stands idle, and that it only makes money if saving time and therefore if moving.

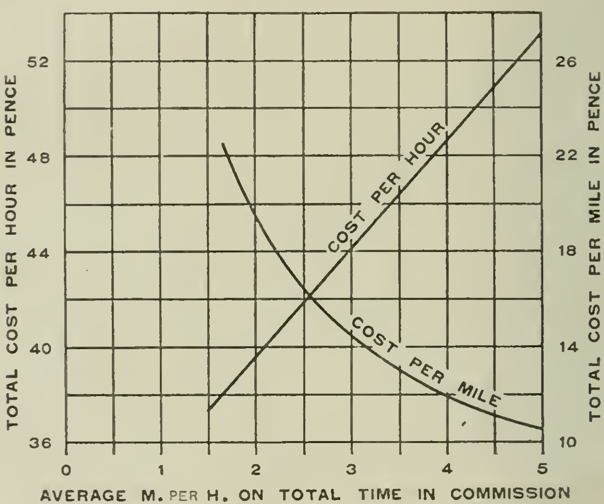
The comparatively high capital cost of all mechanically or electrically propelled vehicles and the shortened working day necessitate the fullest use being made of them, and advantage should be taken of all accessory apparatus which will cut down the time lost in loading or unloading or enable the vehicle to carry a greater load.

Cost of Mechanical Traction.—A normal day's work of 10 hours for a vehicle used in town delivery work may be analysed as follows: running 3 hours, meal 1, loading 3½, unloading 2½ hours, from which it is seen that by saving even only one hour out of the two latter items the running time (which is the true money-earning portion) can be increased by 30 per cent. Such savings can be more easily realized perhaps by taking the actual case, say, of a 3½-ton vehicle costing £1,000. The capital and driving charges of this machine would amount to roughly £300 per annum, or 2*s.* 6*d.* per hour whether moving or standing, to which must be also added the loss in earning capacity. Fig. 3 (page 668) shows the effect on cost per mile of increasing the miles run per day or the average m.p.h. taken on the total time in commission, that is, without lengthening the working day, but by decreasing the standing time, the vehicle is made to do more work, and the standing and driving costs are therefore spread over a greater mileage.

The engineer is still, however, helpless in the face of existing haphazard methods of operation where "waiting turn" at docks, warehouses, etc., is still in vogue, with consequent idleness and waste of time. Pooling has been proposed, and with it there apparently comes the necessity of standardization, to a certain extent at least, of body design, floor height, etc., whilst the possible use of removable bodies should not be lost sight of. Various means have been proposed for increasing the efficiency of motor-traction, and an examination of these might prove useful.

Time-saving Devices for loading and unloading.—Since the average vehicle loses more time at the loading point than at any other part of its route, devices which assist rapid loading are perhaps most numerous. Removable bodies or variations of the demountable principle are probably the most effective of such devices, and isolated cases have been in use for a considerable number of years. The "Lancashire" flat, for instance, as used for concentrated heavy loads of linoleum and cotton goods, and lifted off by the ordinary

FIG. 3.



goods yard cranes, has been in operation for at least 20 years, whilst removal contractors have made use of the system by arranging for the bodies of their pantechnicons to be made detachable. It is obvious that if an extra body can be left at the loading dock to be dealt with whilst the vehicle is out on its round and satisfactory means are provided for changing the bodies, the delay to the motor will be reduced to a minimum. It will usually be found sufficient to employ three bodies: one loading, one in transit on the vehicle, and one unloading at the other end of the route.

A simple arrangement illustrated by Fig. 4 is to provide plain flat bodies and sets of pulley-blocks which are suspended from the roof of the warehouse, and for men to lower the bodies on to the vehicles when these have been backed into position. The Curtis Publishing Co. are reported to have increased their haulage per day on four vehicles by 14 tons by this means, which, however, is open to the objection that a considerable amount of labour is required for lifting and lowering the bodies. This arrangement is also only applicable where a strong roof or overhead structure is available whilst the lifting gear confines the loading to fixed points and would have to be provided for each body in use. An

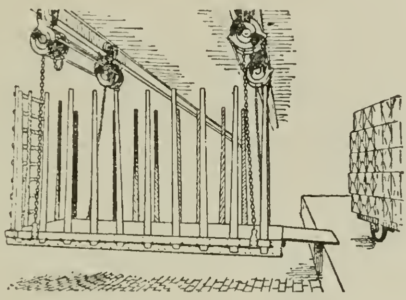


Fig. 4.—*Pulley-blocks supporting flat bodies to be lowered on to vehicles.*

improvement on this was designed by the Author some time ago in which the lifting gear was embodied in the motor-chassis, the lifting gear then being always available irrespective of position, and the bodies were supported at one end by sling chains from the roof and at the other on the edge of the loading deck, as shown by Fig. 5 (page 670). Where the roof is strong enough to carry the weight and there is no necessity to move the bodies from the loading point until required by the motor-vehicle, this is a very satisfactory method and much the quickest in operation. If it is necessary to move some of the loaded bodies to provide space for others, they can be accommodated on stands, as shown by Fig. 6.

In an extensive system using such an arrangement of body, a cheap slow-speed electric vehicle which might be designated the conveyor, and used to lift, convey, and deposit the bodies as dealt

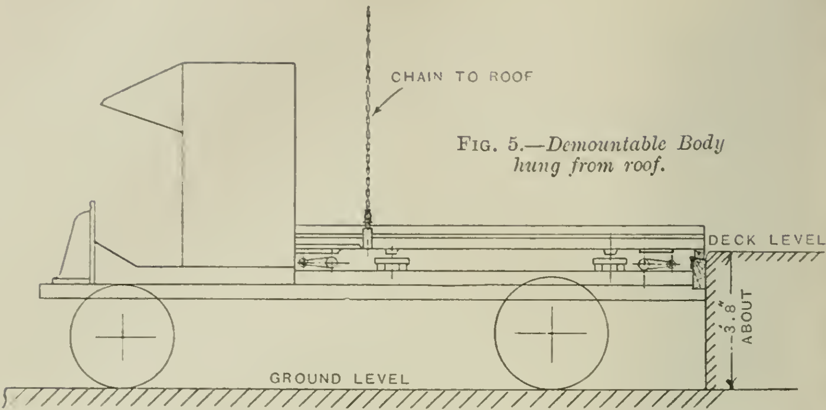
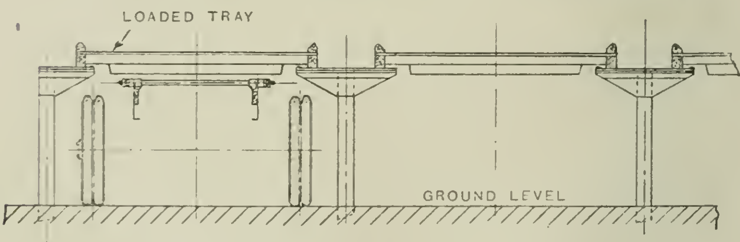


FIG. 5.—*Demountable Body hung from roof.*

with, could in the case of railway transport supply the link between the wagon and the road vehicle without any upheaval of existing methods or the provision of expensive machinery and buildings. Full loads between stations would be dealt with on the same bodies, but by employing overhead cranes for the transfer from rail to conveyor or road vehicle.

A further modification, and one used where no means exist for supporting the bodies, consists of providing special legs with hinged feet which are turned up out of the way to give road clearance

FIG. 6.—*Cross Section of Stacking Frames for Demountable Bodies.*



when travelling. Fig. 7 shows such a body as fitted to a 2-ton electric vehicle by the Edison Accumulator Co., whilst Fig. 8, Plate 19, shows the operations in detail of picking up a loaded body. The lifting gear is driven by a separate small electric motor

which is arranged with an automatic cut-off to prevent overrunning. To provide for easy entrance of the chassis under the body, the front legs of the latter are made to pull out to give additional

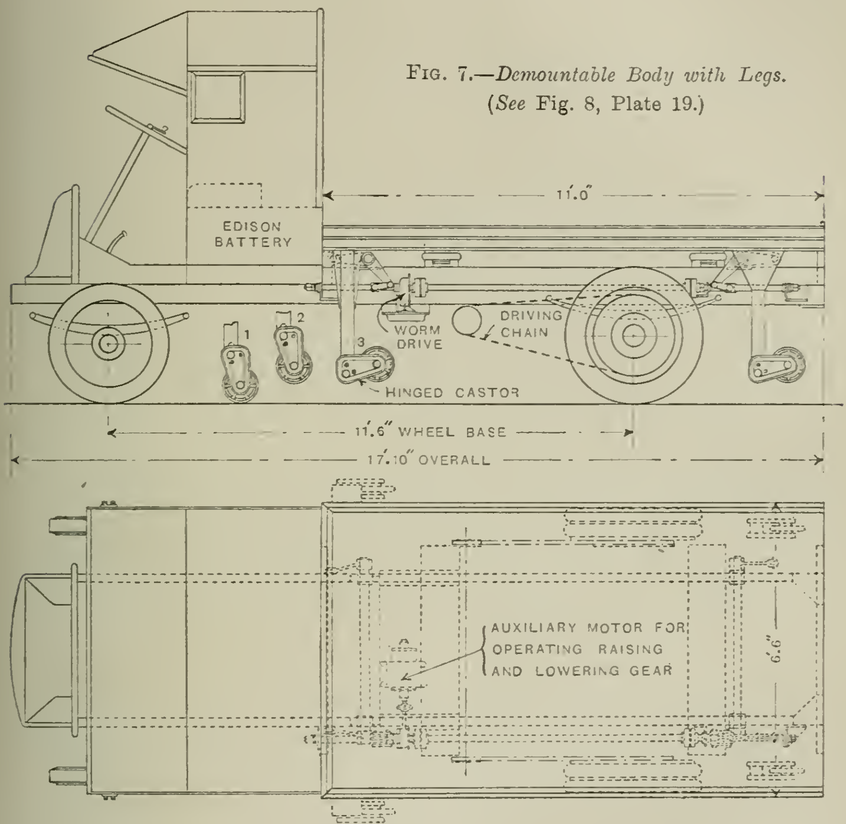
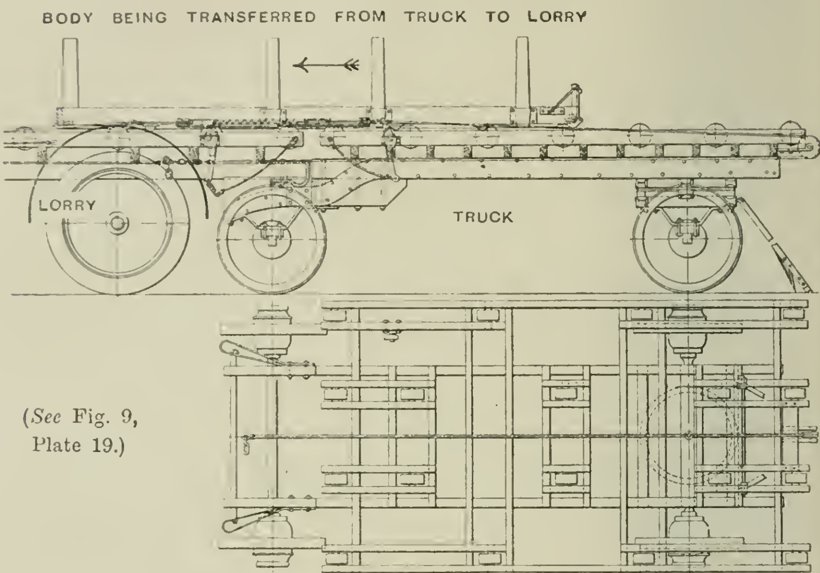


Fig. 7.—*Demountable Body with Legs.* (*See* Fig. 8, Plate 19.)

clearance (position 1, Fig. 7), and when pushed in to the normal position present no obstruction in traffic (position 3). The provision of lifting gear of this description allows the driver to discharge a loaded body and take on another in a very few minutes unaided and with no special exertion.

Several methods employing bodies which can be rolled off are in use; one, for instance, is that shown in Fig. 9, Plate 19, and Fig. 10, and known as the Stamper loading truck.* In this system at each end of the journey a truck or trolly is provided on to which the body

FIG. 10.—*Loading Truck (Stamper).*



(*See* Fig. 9, Plate 19.)

is transferred from the lorry by means of a winch. The truck is arranged with a standard type of forecarriage and drawgear which enables it to be moved if desired. The truck has no springs, so that the height remains constant, and consists of a framework provided on the top with a number of rollers, a similar set of rollers being fixed on the motor-chassis. The tail end of the truck is formed with sloping guide-plates which engage with rubbing plates attached to the rear of the motor-vehicle, so that when backed together their heights and that of the two sets of rollers are the same. A certain amount of play is also allowed on the axle-arms

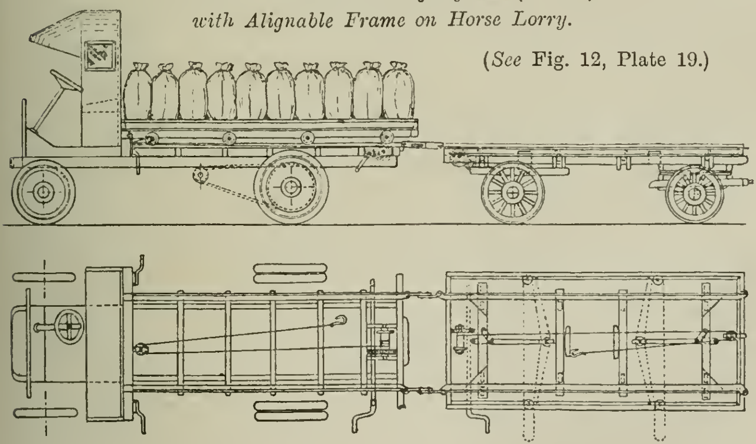
* See *Engineering*, 30th March 1917.

to facilitate centring. On the under side of the body four angle-irons are fixed lengthwise, which act as runners and prevent side movement. The method of operation is, for the motor lorry on its arrival at the loading point to back up to the loading truck so that the foot-irons enter the guides on the rear of the truck, and on further backing taking place the foot-irons slide up these, so ensuring that the two platforms are brought to the same height. By means of the winch on the motor, the body can then be drawn across into position where it is automatically locked as it passes over a pair of spring-operated bolts.

Another system, using tender-lorries and designed with a view to obviating trouble in obtaining accurate alignment between the two vehicles for the transfer of the bodies, is that illustrated in Fig. 11 and Fig. 12, Plate 19, and known as the D.C.C. system, the inventors being Messrs. Dalziel, Crocker and the Author. The

Fig. 11.—*Removable Body System (D.C.C.) with Alignable Frame on Horse Lorry.*

(*See* Fig. 12, Plate 19.)



main underlying idea in this case is the provision of a loose frame carrying the body and which can be twisted in any direction or traversed across so as to bring its rails into true alignment with those of the other vehicle, the two vehicles having previously been only approximately and quickly placed in alignment. The rollers

in this system are fitted to the bodies, which run on rails carried by the vehicles, whilst disused horse-lorries are generally made use of as the tender-vehicles. Short telescopic rails connect the two vehicles, and the rails on the tenders are formed into loose frames carried on rollers and controlled by levers and chains from either side. In this case after the vehicles have been roughly positioned and the connecting rails dropped into their sockets, one or both ends of the frame carrying the rails on the tender are drawn across until the rails are in alignment with those on the motor-vehicle. It will be readily seen that an operation such as this is necessarily much quicker and easier than trying to meet the same end by see-sawing the motor back and forward. A feature of the D.C.C. system is that the body can be taken off or put on to the tender-lorry at either end whichever happens to be handiest at the moment. With any of these foregoing arrangements, bodies can be exchanged in a few minutes, and an added advantage from the loader's point of view is that the loading can be carried out at his convenience and to the best advantage. In some cases it is desirable that bodies which have been dealt with should be removed from the loading deck to make room for others, and, when tender-lorries are in use, this can be readily accomplished by a horse or cheap form of tractor. The warehouses and yards of private traders, however, may not allow of the use of tender-vehicles, in which case the frames for alignment may be placed on the decks so that the bodies may form part of the floor space. By such an arrangement one of the objections to the Gattie system, namely, the difficulty of handling the containers at the average trader's premises, can be readily overcome.

Trailers.—What amount in effect to removable bodies are the trailers, semi-trailers and road trains, whilst they have the advantage under favourable circumstances of enabling a greater load to be hauled by the same power unit. Quite extraordinary claims have been made for the performance of trailers, especially in America, and no doubt for bulk loads and on easy routes they have their place, but the wholesale adoption of trailers behind

ordinary vehicles carrying loads cannot be justified, as a trailer takes power to haul it, reduces the speed of working, accelerates depreciation of the mechanism, and increases tyre wear. In this connexion the law regulating the construction and use of trailers has done much to limit their adoption, the main points to which exception may be taken being that the speed of a motor-vehicle hauling a trailer must not exceed five miles per hour and that it must not haul more than one at a time.

There is no reason whatever why trailers should not be operated safely up to ten miles per hour, and this would at one sweep double the nominal capacity of the combination for doing work, and by fitting them universally with rubber tyres no more damage would be done to the roads. For bulk loads, trailers or road trains drawn by suitable tractors form a very economical combination, but their use in congested areas should be confined to night work. The tractors for such work must be specially designed, as they require to be very robust to withstand the sudden and violent strains to which they are subjected in starting and braking the trailing load, whilst in tractors of the internal-combustion type, as the power unit is run more nearly at full load for considerable periods than is the case in ordinary vehicles, particular attention should be paid to the cooling surfaces, and it is also usual in this type to provide more than the usual number of gear changes. A comparison between the full trailer and the semi-trailer is interesting as showing the work for which each type is most suitable. The full trailer, examples of which are shown in Figs. 13, 14 and 15, Plate 20, is a separate vehicle on four wheels, and can be more readily left for loading and unloading whilst the tractor is away on other work, but the combination has the disadvantage of being very deficient in manœuvring properties, especially in backing. This has been got over in trailers of the type Fig. 15, Plate 20, by the provision of individual steering-gear and, when desired, forecarriages at each end which can be locked at will. In the one shown the draw-bar is locked to the forecarriage by a pin when being hauled forward and the hand steering-gear disengaged by means of the clutch seen just above the platform, whilst in backing the draw-bar is left

free and the movements of the trailer directed by the hand steering-gear. Trailers of this type can be readily adapted for use with tipping bodies as is shown by Fig. 14. It should be noted that draw-gear for trailers should be constructed with double action springs to take care of the starting and braking shocks.

Semi-Trailers.—With the semi-trailer the tractor partly carries and partly hauls the load, the front end of a two-wheeled vehicle being carried on a platform directly over the rear or driving wheels. About 40 per cent. of the load is usually taken in this manner, the remaining 60 per cent. being carried on iron-tyred wheels. A load of 10 tons can be easily dealt with by this combination without the truck having to be made excessively heavy, as it otherwise would be if designed to carry the total load, if that were feasible under axle-weight restrictions. Additional load on a semi-trailer provides additional adhesive weight, but never more than 40 per cent. of the total. The three-axle arrangement thus obtained is allowed to run up to 12 m.p.h.; it is more compact than the four-axle with two independent vehicles, and much easier to manœuvre, being somewhat on a par in this respect with a horse and lorry, although the side-stepping action of the horse can never be wholly equalled. By propping up the front end, the trailer may be left for loading or unloading, but this operation takes more time than the uncoupling of a four-wheel trailer, with which, however, there is always the danger of a man being crushed. For this reason some form of automatic coupling is advisable, which should then be arranged for release by the driver without his having to leave his seat. A coupling of this description in use on small warehouse trollies is shown in Fig. 16, Plate 20, and described in *The Railway Gazette* of 21st Jan. 1916. Some modification of this design would be required to meet the higher speeds and greater weights encountered in road haulage.

A typical example of the semi-trailer combination is shown in Fig. 17, Plate 21, which is a Knox tractor of 7 tons capacity in use by the Great Western Railway Co. The tractor is so constructed that its chassis proper ends at the chain-drive sprocket

cross-shaft; the rear axle is attached to this chassis through the medium of the radius-rods and the weight of the rear end of the chassis is carried on it by the rear ends of two long cantilever springs. The rear axle and wheels are therefore an entirely separate unit so far as carrying the load to be hauled is concerned. A separate frame cross-braced and carrying a central pivot for receiving the semi-trailer pin is mounted upon two stiff semi-elliptical springs, which are in turn anchored to the rear axle. The front end of the semi-trailer is thus carried by the rear wheels of the tractor only; the more flexible springing of the tractor chassis proper remaining constant and independent of the load carried on the semi-trailer. The legs of the trailer hinge up under the body when the latter is in the running position. An electric tractor and semi-trailer refuse-wagon as made by The General Vehicle Co. is shown in Fig. 18, Plate 21, the connexion being made by a rocking fifth wheel and cone bearing on the tractor with the cup on the trailer. Fig. 19, Plate 21, shows an interesting variation of the three-axle arrangement with four-wheel tractor and trailer. This is a four-wheel refuse-wagon drawn by a Lloyd electric tractor, which after coupling up has its rear wheels lifted off the ground by means of a screw-gear. Such a combination gives a three-axle machine with good manœuvring qualities, but necessitates a front-wheel drive and steer, which is obtained by fixing an electric motor directly to each front wheel which is driven by internal gear. This is the Mossay system used in the construction of the smaller-sized "Orwell" vehicles built by Messrs. Ransomes, Sims and Jefferies.

It has not been found advisable to use four-wheeled trailers with petrol-vehicles for the reasons already given, but numbers of two-wheeled trailers have been employed for special military purposes such as for the conveyance of aeroplanes, etc. Fig. 20, Plate 22, shows a Thornycroft lorry with standard body and two-wheeled trailer used by the Government of India. The trailers are used on the plains and the lorries alone in the hilly regions on the Afghan frontier. Another method which has been adopted to enable greater loads to be dealt with is the four-wheel drive, in

which 100 per cent. of the weight is used to give adhesion for driving, instead of the 75 per cent. which may be considered as the usual maximum with the ordinary two-wheel drive.

It is very questionable, however, whether the conditions in this country are ever severe enough to warrant the extra expense in first cost and maintenance occasioned by the adoption of this design of vehicle, although it has much to recommend it in the case of heavy tractors. Fig. 21 (page 679) illustrates the capabilities of a four-wheel drive petrol-vehicle. Vehicles constructed on the caterpillar or track-laying system are not likely to come into use for general purposes, and they will no doubt be restricted to work on bad roads and rough land or for military purposes. The question of cross-country transport was at one period of the war of very vital importance, and as the tank construction was not suitable for such work, the tractor illustrated by Figs. 22 and 23, Plate 22, and known as the "Newton," was evolved. It was designed for mass production at a low cost, and had the War continued it would have been turned out to the number of some 20,000; its construction in quantity had, as a matter of fact, already been begun, and a few hundreds had been completed when the Armistice was signed. The idea underlying the design was the utilization of standard peace time material, such as conveyor chain-links, motor-car engines, boiler-plates, etc., all of which could be procured and produced easily in large quantities. These vehicles had a very low intensity of ground pressure, and with the addition of a few sand bags would have been capable of carrying men and materials quickly and comparatively safely into the enemies' territory over the worst of ground surfaces. Fig. 22 shows the first experimental tractor, whilst Fig. 23 shows it as finally produced. The objection for commercial work to all machines of this type constructed on the track-laying principle is the heavy upkeep due to wear and tear of the multiplicity of joints, a construction which does not appear to be readily capable of improvement. In cases where demountable bodies or trailers may not be applicable, other means may be utilized to assist in quick loading, such as overhead cranes and runways, spiral and straight chutes, conveyors of various

Figs. 21, 24–29.

Sketches of Devices for Quick Loading and Unloading, etc.

Fig. 21.

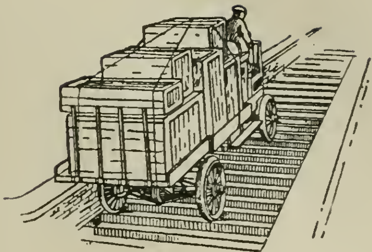


Fig. 24.

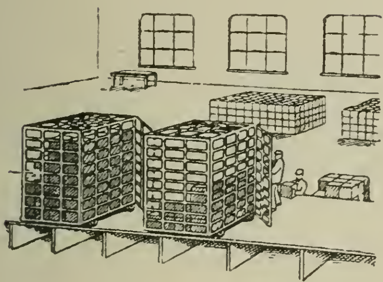


Fig. 25.

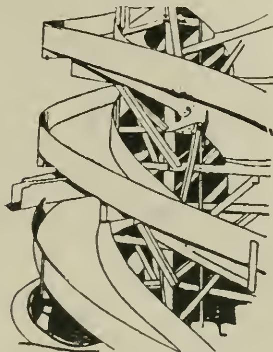


Fig. 26.

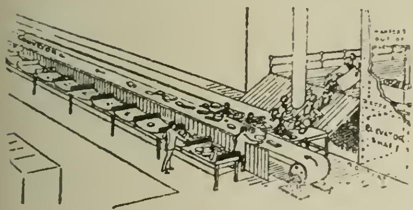


Fig. 27.

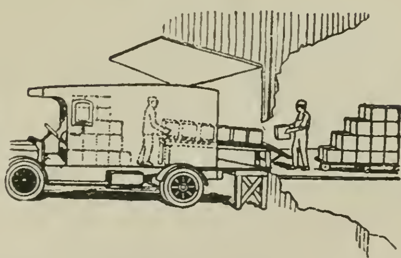


Fig. 28.

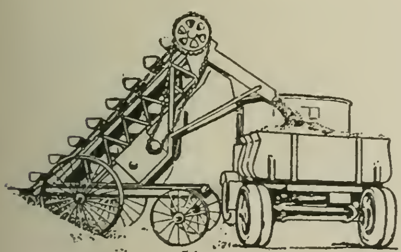
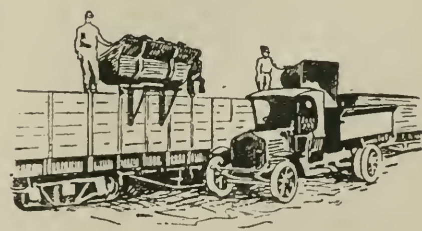


Fig. 29.



types, and hand and electric baggage trucks with elevating platforms. Little need be said as to the details of these various devices which are familiar in other branches of engineering and contracting work. Figs. 24–29 are self-explanatory and illustrate the application of some of these aids to quick loading, most of which can be utilized for the reverse operation, namely, that of unloading.

Tipping Lorries.—Unloading, as a rule, presents less difficulty than that of loading, and in the case of rough material such as sand, road metal, etc., the now familiar tipping body is the most commonly used. Examples of these are shown in Figs. 30 and 31, Plate 23, whilst Figs. 32, 33 and 34 show more recent variations of the same to suit particular requirements such as sideways dumping, dumping coal down pavement holes, etc. Electric tipping lorries, of which Figs. 30 and 31 are typical examples, are extremely useful

FIGS. 32-35.—*Tipping, Sideways Dumping, and Pavement Hole Dumping Lorries, also Unloading Machinery for Lorries.*

FIG. 32.

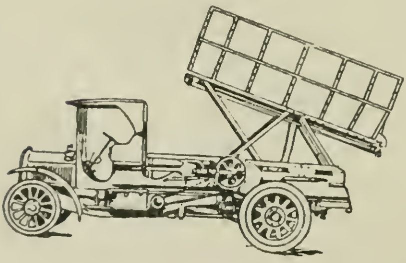


FIG. 33.

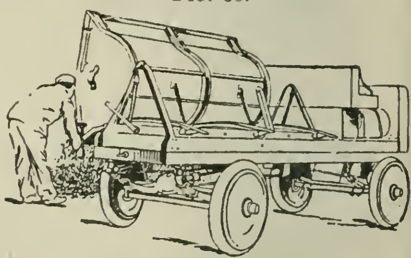


FIG. 34.

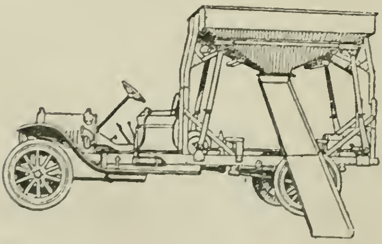
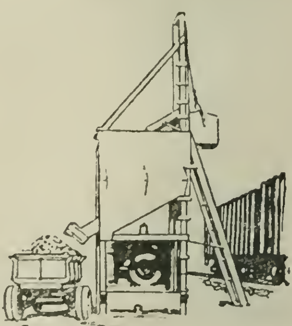
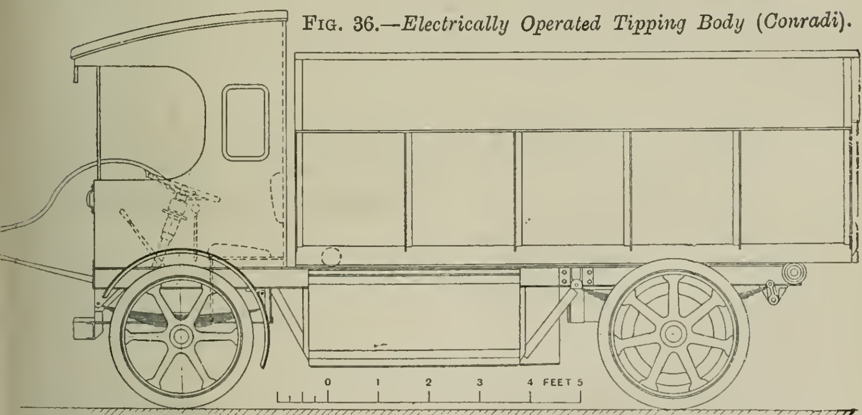


FIG. 35.



for refuse disposal, coal transport and such work, the tipping gear being either hand- or power-operated by a small separate electric motor. In the former of these two, The Orwell, the tipping gear is arranged with two screws of different pitch, and in such a manner that during operation the body is carried to the rear at the same time as it is being tipped, whilst in the latter, G. V.-Constable, the body is moved out by a single screw until a balance is obtained and then tipped, the power required being thereby reduced. A special feature is the method of mounting the door so that it remains in position whilst the body falls away from it and leaves a very free opening. The advantages of the "electric" for municipal and all town collection and delivery work are being rapidly recognized, and a great increase in this type is to be looked for in the near future. An electric vehicle which has been specially designed by the Author for such house-to-house visitation work is shown in Fig. 36. In this case the entrance is at the front, the

Fig. 36.—*Electrically Operated Tipping Body* (*Conradi*).



driver's cab being dropped between the side members of the chassis to such an extent that only one step up is required to enable the driver to mount, considerable time and energy being thereby saved. A special "inching" or "leading" control is also provided when desired for use in refuse collection, whereby the vehicle can be steered and driven slowly from ground level, thus obviating the

necessity for the driver's mounting into the driving seat for a movement of probably only a few yards between stops. This gear is "foolproof" and can instantly be put out of action to allow of ordinary driving being resumed. It has been shown for clearness at the front of the vehicle, but might be equally well used at the side. Fig. 35 (page 680) shows the possibilities of using specially designed unloading machinery.

Heavy goods which cannot be dealt with by tipping bodies may be lifted off by self-contained cranes, either hand- or power-operated. Fig. 37, Plate 23, illustrates one of these which has been in use for logging and similar purposes, as fitted by the Yorkshire Motor Co. The lorry shown is one of the firm's standard 5–6-ton vehicles, capable of speeds up to 8 miles per hour and of hauling a further load of 4 tons on a trailer when required. The crane, which is fixed behind the driver's cab, has a radius of 7 feet 6 inches and a clearance of 5 feet 6 inches between hook and platform. It can lift 2 tons and is driven off the engine by friction-clutch put into operation by depressing a foot-lever on the driver's foot-plate.

An ingenious piece of apparatus which may be considered as a direct product of the War is the Wilkins truck emptier illustrated in Figs. 38 and 39, Plate 24. This is an adaptation of the roller-blind shutter which, as an unloading device, has the advantage that any fraction of the load can be readily dumped as desired, whilst it can also be used to facilitate loading.

Barrows.—In the loading of all heavy goods, barrows of some description are necessary, and for the actual picking up and moving of packages it is difficult to find a more efficient machine than the so-called miller's two-wheeled hand-barrow, the toe of which can be so conveniently inserted under a package and used as a lever to lift and carry the same. The capacity of such a barrow, however, is strictly limited, and if any considerable distance has to be covered it is advisable to adopt power haulage. Considerable numbers of hand-operated trucks with lifting tops and of capacities up to 15 cwt. are now in use. These are sometimes known as jack-trucks, being, as the name implies, a combination of lifting jack and truck,

and are made in various forms to suit individual requirements. Figs. 40 and 41, Plate 24, show two Hardaker trucks, the first being capable of lifting 15 cwt., whilst the second has a special U-frame designed for use with boxes arranged for dealing with quantities of small heavy parts. Where long runs obtain, electric baggage trucks carrying loads up to 2 tons or acting as tractors for trains of small trailers are useful in expediting the loading and unloading of the road vehicles, whilst for special cases they can be provided with power-operated lifting platforms and loading trays or small cranes for heavy loads. Figs. 42, 43 and 44, Plate 25, illustrate this type of apparatus as manufactured by the Edison Accumulator Co. A lifting platform truck operating on war material is reported to have dealt with 150 tons of material in one day, whilst trucks working on long runs with trailers regularly deal with 200 tons and upwards per week. Where there is a steady stream of standard pieces to be transported, it pays to have the trailers specially designed to suit the work, saving in time being thereby effected in packing, arranging, and securing the articles.

Characteristics of Motor-Vehicles.

Turning now to the various types of vehicles available, it would be well to consider first their general characteristics so that one may the more readily note the fitness or otherwise of the various details of design which go to the make-up of the vehicle as a whole and the fitness of that whole to fill the rôle for which it is most obviously suited. Self-propelled vehicles may be driven by steam, electricity, or internal-combustion engines using gas, petrol or benzol, paraffin or alcohol as fuel, whilst the mixed petrol-electric system may also be noted.

Steam.—The steam vehicle for commercial work is a most reliable and useful machine, but is handicapped against universal adoption by the boiler, which does not appear capable of further improvement in the necessary direction. The boilers of such vehicles are largely of the fire-tube variety, which means that they

are costly and heavy and cannot readily be designed in the smaller sizes. This and the fact that the weight of supplies of fuel and water is considerable no doubt account for the scarcity of "steamers" below about 3½-ton capacity, and altogether their qualifications seem to suit them best for heavy hauls at moderate speeds over comparatively long distances. "Steamers" for light passenger cars are still being turned out steadily in America, but in relatively small numbers, and not at all in this country.

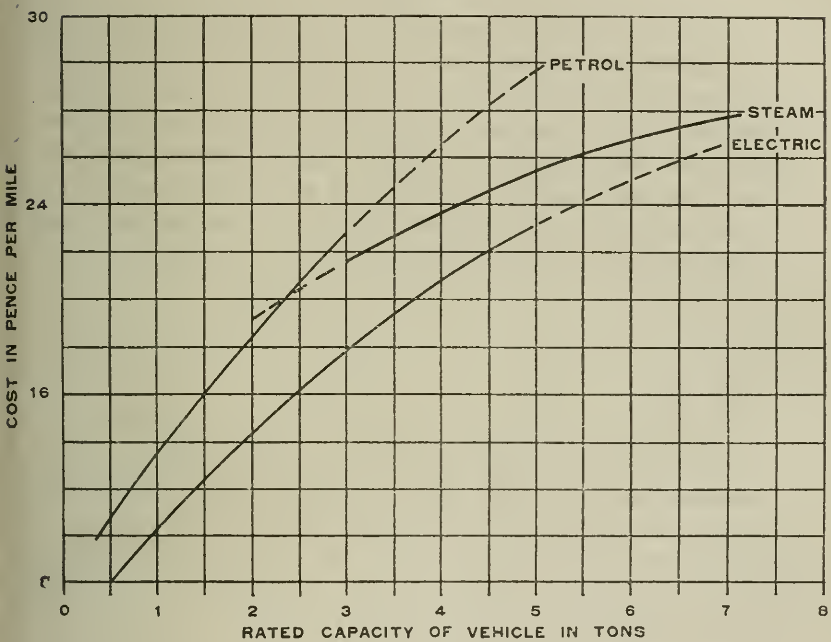
Petrol.—What is popularly known as the petrol vehicle has a characteristic governed by that of the internal-combustion engine on which it depends for its power of locomotion. This motor is essentially a one-speed machine with comparatively little flexibility, and has therefore to be combined with some form of starting and speed-varying gear. The necessity for gear changing has been reduced to some extent by the fitting of excessively large engines, but only at the expense of fuel consumption, car tax (in the case of passenger cars), etc. The petrol vehicle is best suited, therefore, for work involving few stops and high speed, where starting and gear changing, with the attendant racking stresses, will be a minimum.

Electric.—The electric vehicle, on the other hand, having no change-speed-gear, low maximum speed, high acceleration, no reciprocating parts, easy control in traffic, and limited radius of action is best fitted for short-distance frequent-stop service through congested areas, although it is also very suitable and has been used as a tractor for heavy haulages.

Comparison of the three Systems.—It will therefore be observed from a consideration of the characteristics of the various types of machines that there should be little competition between them, each having a fairly well-defined sphere of usefulness. The competition is rather between horse and motor, and even then only for short-distance work, where in some cases the former still has some advantages. Fig. 45 shows the relative positions of these three main classes of vehicles when their running

costs, based on their nominal capacities, are compared, and it will be noticed that the "petrol" after the 3-ton point is reached has to give place to the "steamer," whilst the latter also approaches very closely to the "electric" after 5 tons is reached. Beyond capacities of 5–6 tons it is probable that the electric would be built as a tractor with trailer or semi-trailer. The deductions to be drawn from this chart agree very well with the conclusions

Fig. 45.



obtained from the consideration of the characteristics of the type of machine, and the approximate field of usefulness when the conditions are favourable to the type is shown by the solid line. The very wide range of "The Electric" should be noted, and if the "Petrol-Electric" be admitted to this class, all work excepting where speed is a *sine qua non* comes within its scope.

It is only in Britain, and perhaps more especially in England,

that the steam-vehicle has been used to any considerable extent, ample supplies of suitable fuel no doubt contributing largely to this result. The boilers, as previously indicated, are chiefly of the fire-tube variety, whilst the locomotive type predominates. The vertical boiler is believed to be in use on four makes of vehicles with satisfactory results, an example of the "Sentinel" water-tube boiler being shown in Fig. 46, Plate 26, which is conspicuous for its simple construction and the ease with which it can be opened up for inspection. This can be accomplished by undoing two joints and dropping the inside out entirely, Fig. 47, without disturbing any of the joints on the outer shell. The position and type of engine is a moot point in the design of steam-wagons, and from the success attending both the undertype and overtype, the simple and the compound, there appears very little to choose between them all. The "Clayton," Fig. 39, Plate 24 (end view only shown), is an example of the latter with a compound overtype engine, whilst the "Sentinel," Fig. 46, Plate 26, is fitted with a double cylinder simple undertype engine. The undertype engined vehicle no doubt comes out shorter and therefore has some advantage from the manœuvring point of view, whilst it is also claimed in some cases that a lighter vehicle can be produced.

Steam tractors and traction engines have been improved chiefly in the direction of increased economy by the introduction of compounding, etc., whilst many of them are now fitted with rubber tyres. Fig. 48, Plate 26, shows an up-to-date steam-tractor on rubber tyres built by Messrs. Foster and Co. of Lincoln. Such a machine is capable of developing from 14 to 20 h.p. and of hauling a gross load of from 8 to 10 tons up a gradient of 1 in 8. The weight in working order is about $5\frac{3}{4}$ tons.

The heavier type of steam tractors, known by the generic name of "traction engines," are fitted with engines and boilers capable of developing on the larger sizes 50–60 h.p. and of dealing with loads up to 25 tons, whilst their weight in working order may be anything up to 16 tons.

Petrol-Engine Tractors.—One of the most powerful petrol-

engine tractors is shown in Fig. 49, Plate 26, and is a Foster 105 b.h.p. tractor capable of hauling 30–35 tons at a speed of 5 m.p.h. The engine has a governed speed of 1,000 r.p.m. and transmits its power through worm-gear to a differentially-geared cross-shaft which carries a pinion on each end, gearing into toothed rings on the road wheels. The rear road wheels are 8 feet diameter and 2 feet wide.

The petrol vehicle as a whole is well known and has not altered greatly in general design within recent years, although it has been improved considerably in detail design and by the use of alloy steel in construction; both of these have made for greater reliability, freedom from breakdown and reduction in weight. The greatest strides in the use of the internal-combustion engine for transport and haulage work have been made in tractor design for military and agricultural work, much of which was the outcome of necessities occasioned by the late War. Purely agricultural tractors cannot bulk largely in road transport, owing to damage which would be caused to the roads by wheels made suitable for work on the land, and the logical conclusion is that the tractors designed for work on the land should be restricted to such work, and that the haulage of the produce on the roads be carried out by road vehicles of the ordinary type, or where badly made yards or field entrances have to be negotiated frequently, by four-wheel drive machines.

Electric Vehicles.—Electric battery vehicles, although rapidly increasing in number in this country, are not a very familiar sight in the streets, and, except to those specially interested in them, may be looked upon as a new aspirant in the field of mechanical road traction. It may be pointed out, however, that heavy electric vehicles have been in use in America for about eighteen years, many of the original vehicles being still on the road, whilst in England and on the Continent numbers have been in use for many years. In Greater New York it is understood that about 43 per cent. of the total number of vehicles used for commercial purposes are electric.

After the failure of various attempts at battery traction between 1885 and 1898 it was practically abandoned in this country, but in America, France, and Germany it was continued, with the result that, especially in the former, it was soon on a fairly satisfactory basis. Great credit is due to American engineers, who slowly but surely overcame the mechanical and electrical disabilities of the lead battery and brought the alkaline cell up to the point of being a commercial success. The chassis of some of the early machines which are still running are reported as showing no deterioration whatever, which is no doubt due to the low maximum speed and absence of vibration in the driving mechanism. The advantages of the "Electric' might be briefly stated thus :—Cost of energy is low, and until the effect of war conditions was felt had been steadily decreasing; no power is consumed whilst at rest; they can be easily controlled by unskilled labour, horse drivers being taught to drive efficiently in a few days or even hours; the overall length is short; they have a high figure of reliability due to simple construction and the absence of rotating ports, and consequently low repair costs; they are clean, sanitary and free from fire risks. The most common, in fact practically the only, criticism levelled at the electric vehicle is its low speed, but what is required for town work, where this type has its field, is the maintenance of a reasonably high average speed. This is obtained by electric vehicles because of their easy control and high acceleration, and numerous observations go to show that when compared with petrol vehicles on the question of speed, the latter, with probably 75 per cent. greater maximum speed, has no time saved to its credit at the end of the day. The *Central Station* of America published some time ago the following results of a series of tests between a petrol and an electric lorry geared respectively for a maximum speed of 12 and 18 miles per hour. The course was triangular and the roads good. Duration of stops in the case of (*a*) 2 minutes, (*b*) 1 minute, number of stops 24, distance between stops 0·42 mile.

	Average Speeds.	
	Electric	Petrol
(*a*) Leg 1 level	10·76	9·41
2 up	7·08	8·85
3 down	11·12	7·2
Average	9·65	8·48
(*b*) Leg 1 level	11·4	10·08
2 up	6·9	7·83
3 down	11·8	10·56
Average	10·03	9·48
General ,,	9·84	8·98

This shows the average speed of the electric lorry to be approximately 10 per cent. higher, although geared and powered for a 30 per cent. lower speed.

The reliability of the electric vehicle is becoming proverbial, and if need be it would be quite feasible to run an electric vehicle for 365 days in the year. Brookman, in a Paper given at Glasgow, gave the relative ratios of working days to days in commission as electric 95 per cent., petrol 90 per cent., steam 85 per cent., whilst the Author would be inclined to place the electric at 2 per cent. better than this. Little difficulty is experienced in obtaining adequate supplies of electricity, and the position in regard to this is improving daily.

Electric power is exceedingly flexible in its application and will readily admit of vehicles being designed for special purposes in a way which will allow of the maximum possible duty being obtained from them.

The "Fram," which was a French machine, is an instance of the possibilities of designing electric chassis for special purposes, and these machines were used in large numbers for refuse

collection by the Municipality of Paris. The power unit is complete in the form of a detachable forecarriage with battery and motors coupled direct to each wheel. A feature of the Fram control is that steering is assisted by accelerating the outside motor above the speed of the other by means of an automatic attachment to the steering wheel. This throws 27 cells out of the complete 44 on to the motor, which requires to run the faster, as against 17 on the other. The front wheels revolve on a fixed axle, and in steering, the whole forecarriage turns as in a horse vehicle, an extremely large lock being obtained. Regenerative braking is used, and in descending stiff gradients currents up to 80 amperes are returned to the battery.

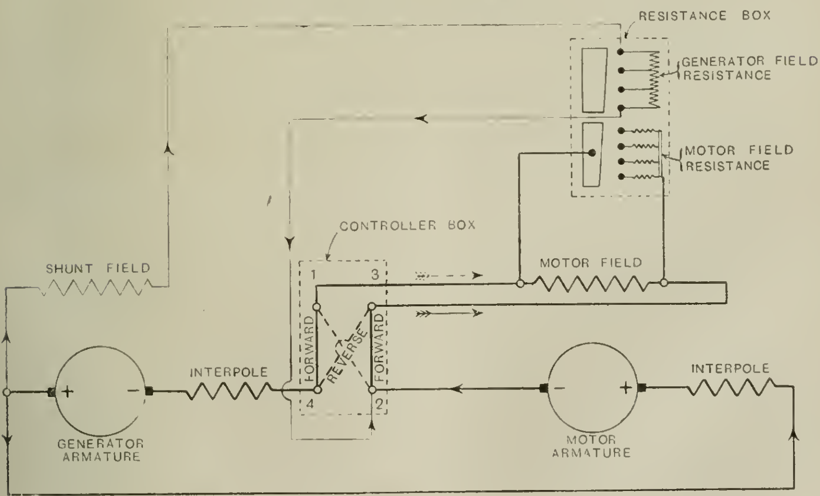
Wheel drives, where the motors are built into the wheels, have been used to a considerable extent, and these allow of two or all four wheels being driven and also a certain amount of additional latitude in the design of special purpose chassis. In this class beside the "Fram" and the Mossay we may note the Cedes, in which a slow-speed gearless motor is built into the wheel; the C.T. internal-gear drive, the motor and pinion being concentric with the gear ring and engaging through a cluster of idler intermediate wheels, and the Couple Gear in which a high-speed motor is carried in a horizontal position within the wheel itself and having a bevel pinion on each end of the shaft gearing with two bevel rings on which the road wheels are mounted. The motor is set at a slight angle to the plane of the wheel so that the pinions engage with their respective halves of the racks whilst being free of the other half. A reduction of 25–1 is used and an efficiency of 97½ per cent. is vouched for by the American Bureau of Standards.

With regard to the driving gear in general, final chain drives are efficient when new, but tend soon to become noisy owing to the multiplicity of small joints which are exposed to dust, dirt and the action of the elements, and which it is very difficult to keep lubricated. Bevel-gear drives, double reduction and worm gears as usually designed, all require a heavier rear axle than the chain drive, and owing again to this increase in weight the gears themselves require to be made heavier to stand the severer shocks

entailed and to which they are subjected. Bevel gears necessitate exceedingly fine adjustment and therefore skilled attention, and for these reasons are not desirable components of a road vehicle. Its use on the heavier vehicles has already been much reduced whilst it is being slowly eliminated from the lighter ones. Worm gear has been much improved during recent years, but its overall efficiency under varying road and load conditions is a very questionable quantity, and its use, especially with electrically driven vehicles, is not at all desirable. Wherever possible spur gear and preferably internal gear should be made use of for the heavier classes of vehicle

Petrol-Electric Vehicles.—To enable vehicles to cope with distances which are beyond the capacity of battery vehicles and yet to retain the advantages of electric transmission, several petrol-electric systems have been successfully developed and used with advantage for omnibus service, especially where heavy routes have to be covered. In the Tilling-Stevens system, illustrated diagrammatically by Fig. 50, the gear-box of a petrol motor is

Fig. 50.—*Electrical Connections.*



replaced by an electric generator coupled to the engine which supplies current to a motor driving a live axle of usual type. Durtnall in his Paragon transmission employs a petrol-driven A.C. generator with what he terms a clutch motor, the case of which revolves fixedly with the engine and generator. Control is obtained by altering the connexions of the clutch motor field so as to drive its rotor at 50 per cent. below, at engine speed or at 50 per cent. above engine speed as desired, the rotor being coupled direct to a standard type rear axle. On the second speed a magnetic clutch drives the rotor mechanically, and the clutch motor electrical losses are then cut out.

The Thomas transmission is a further variation of the petrol-electric drive where the lower speeds are dealt with electrically, but on full speed the electric motor is cut out and its losses eliminated by a direct mechanical drive. Hydraulic transmission with oil as the working fluid has been tried to a limited extent, and the variable-stroke pump driven by the engine gives an easy speed control with an infinite number of steps.

Figs. 51, 52, and 53, Plate 26, illustrate an unique system of electric traction in use in Bradford which, although apparently having only a limited scope at present, may contain germs capable of great future development. A chassis is equipped with two 500-volt 20 h.p. motors with series parallel control and switch-gear to allow of its running on railless routes with positive and negative wires, on tramway routes with earthing-shoe on rail, or off the main routes by means of the battery. The connexions are so arranged that the battery can be placed in series with the motors for charging whilst running on the trolly routes.

The battery consists of 124 Edison B4 cells, which have a capacity sufficient to run the vehicle for ten miles on average roads. The vehicle was put into service in May 1916 and has operated since then chiefly on the collection and delivery of tramway stores, although for the past six months it has also been used on a parcel service between Bradford and Leeds. Fig. 52 shows the vehicle on a railless route with positive and negative wires, whilst Fig. 51 shows it on an ordinary road in condition for

running on the battery. Running on a tramway route involves the necessity of earthing to the rail, and Cross's steering-arm and earthing-shoe shown in Fig. 53 were designed for this purpose. It is obvious that the present arrangement of 500-volt motors and a battery giving 130 volts is not ideal, and can only be a success when running for the major portion of its time on the trolly routes, the battery being used only for short deviations and shunting when collecting or delivering goods.

Mention is made in the report previously referred to, that it would be advisable to provide facilities for carrying out tests on the roads, and the Author would draw attention to the ease and accuracy with which tests can be made on electrical apparatus. Even figures taken in the course of ordinary daily running, which can only be approximately correct, give very useful information, and information with an accuracy which cannot hope to be approached with steam or petrol vehicles. Fig. 54 (page 694), for instance, shows the consumption of electricity throughout twelve months for three vehicles of different capacities and working on different routes. It will be noticed that they all exhibit the same general contour, and bring out the fact that for that particular period there were three peaks of bad weather and road surfaces, whilst in the case of L.M. 9940 the high peak in January was found to be the result of running the vehicle with a broken spring. Defects such as this are quickly detected if such records are properly inspected and the information obtained made use of intelligently. Another instance, showing the ease with which defects are noticed on electric vehicles, occurred when two identical vehicles were run out on trial, supposedly after being properly tuned up, when it was found that one gradually drew away from the other and showed a speed of $1\frac{1}{2}$ miles per hour faster. Investigation showed that the front wheels were out of alignment, and after these were adjusted the two vehicles made the return journey together, only a few yards separating them the whole way.

The following is also a case in point, and, as the results are somewhat interesting, the Author takes the liberty of quoting them here. A short time ago cars without differential were built

in America, whilst similar construction is contemplated in this country, and as the desirability of eliminating the differential was obvious as allowing of simpler and cheaper design, the Author was prompted to run a series of tests with a view to putting a value on

FIG. 54.—*Diagram of Energy Consumption, Electric Vehicles.*

this item of the vehicle mechanism. A 15-cwt. van built by the Electromobile, Ltd., was available, and the series of tests given in the Table * (page 695) were run over the same course, by the same driver,

* *Electrician*, Aug. 31, 1917.

and under the same weather conditions. The vehicle was designed for a speed of 15 miles per hour and weighed, complete with battery, 30 cwt. The electrical equipment consisted of a 60-cell A4 Edison battery supplying current to a double commutator motor and with a modified series parallel system of control. The chassis was arranged with an all-gear drive, the motor driving the live axle through double reduction double helical gear, whilst a bevel differential of normal type was fitted. The differential was securely locked when required, by the insertion of brass blocks between the pinions and meshing with the same, no movement being then possible. The current consumed was measured by a Sangamo ampere-hour meter, and showed current as charged to the battery, not battery output, as is more generally the case. It will be observed from the tabulated results that both light and loaded the consumption of current is greater when the differential is out of action, the percentage difference increasing with increase of load. This is to be expected, as with increased load the tyres will grip the road better and more power be required to cause one wheel to slip when travelling on a curve. As the machine runs entirely on ball-bearings, the whole of the additional power is apparently absorbed by extra wear on the tyres, the face of the tyres, even after only a small mileage had been run, presenting a totally different appearance from that of a tyre running under ordinary conditions.

Condition of differential	Load	Miles	Amp.-hrs.	Amp.-hrs. per mile	Saving per cent.
Locked . . .	Light	18·1	100	5·52	—
Free	,,	18·1	93	5·13	7
Locked . . .	11 cwt.	18·1	125	6·90	—
Free	,,	18·1	110	6·08	12

The question of passenger transport has not been specifically treated, but from what has already been said it will be clear that the bulk of the general work will be carried out by petrol vehicles,

although the steam, electric battery, and petrol electric-driven buses, and where the traffic route is well defined the electric trolly bus and tramcar have their fields. The latter, however, appears to have had its day of usefulness, and in all likelihood will largely be replaced by railless vehicles, the obstruction caused by the track and its cost of maintenance being the *bête noire* of the rail-bound system. Electric runabouts and small closed cars will no doubt come largely into use for town work and be used by ladies for shopping purposes and by professional and business men making calls, their ease of control, cleanliness, quietness, and economical operation, being greatly in their favour.

In conclusion, the goods transport problem might be summarized as follows:—

(*a*) The collection and delivery of miscellaneous traffic from traders having an intermittent daily average of only a few cwt.

(*b*) The collection and delivery of miscellaneous traffic from traders having sufficient traffic to warrant the use of containers or demountable bodies.

(*c*) The transport of bulk loads for short distances.

(*d*) The transport of bulk loads for long distances.

(*a*) calls for the use of economical vehicles with high acceleration and easy control such as is obtained in the electric vehicle, the high powered petrol vehicle on such a service being wasteful of fuel and highly expensive in repairs, and the provision of sorting facilities at one or both ends of the main journey.

(*b*) necessitates the provision of apparatus for loading and unloading the complete bodies with an average weight of probably 3 tons, together with the provision of sorting space at one or both ends of the main journey.

(*c*) The most economical method of dealing with bulk loads for short distances, except possibly in cases where railway sidings and loading machinery is already installed, would appear to be by road-vehicles with bodies designed to suit the particular traffic to be

dealt with, and by the adoption as far as possible of loading and unloading labour-saving devices. The use of road-vehicles has the advantage of reducing the handling of the goods to a minimum.

(*d*) Goods in bulk to be transmitted long distances appears to call for containers of some form suitable for transfer to, and carriage by, rail. This means haulage by road vehicle and the lifting of the body into the rail-wagon by overhead crane. Where machinery exists for even the loading only of material such as, say, limestone, coal and iron, it would not appear to be economical to provide separate containers, the additional tare weight and possible reduction of net paying load more than compensating for any saving which might accrue from their use. The miscellaneous traffic may be long or short distance and all of it required to be sorted. The railway companies and a few of the haulage and express delivery contractors have the necessary sorting space, and, therefore, all miscellaneous traffic should be more economically dealt with by them, and the short distance goods then conveyed by road from the terminal station to points within a radius of, say, 10 miles, arrangements being made so that the vehicles call on the return journey for miscellaneous goods. Handling would be reduced and much time saved on short distance goods, and the uneconomical local goods-stations done away with or only used for bulk traffic where such exists. For all such traffic the road vehicles should be provided with removable bodies into which the traffic can be sorted ready for the vehicle on its return to the station. Traders delivering their own goods would preferably use electric vehicles within a radius of 10 miles and petrol vehicles beyond this, with, when required, "steamers" for the heavier work.

It is to be hoped that sufficient has been said to show the present state of the art of road transport from the Mechanical Engineering side and to point out means of improvement in economy, which are already available. In doing so, further means may now suggest themselves and greater progress be made in the near future. In transport work, as elsewhere, careful selection of the right tools is imperative, and a great mistake is often made by

commercial men in pushing the sale of vehicles of a type unsuited to the particular business under review, a policy which is inimical to the advancement of road locomotion.

The Author has to acknowledge with thanks the kindness of those who have been good enough to place the diagrams, photographs, etc., at his disposal, for the preparation of the illustrations used in the Paper, especially Sir Henry Fowler, K.B.E., Messrs. The B. F. Goodrich Co., *The Electrician*, and *The Railway Gazette*.

The Paper is illustrated by Plates 19 to 26 and 24 Figs. in the letterpress, and is accompanied by 2 Appendixes.

APPENDIX I.

Batteries for Electric Vehicles.

The heart of the Electric Vehicle is the Battery, of which at the moment there are two main types, the lead sulphuric acid combination and the iron-nickel alkali cell, both of which have their field and are equally reliable in operation. There is little to choose between these types on the score of operating costs, but there is the need for differentiating between them according to the local conditions existing in each particular case, so as to obtain the maximum advantage from the vehicle at the lowest cost. Roughly, if the flat plate lead battery costs £100 and lasts one and a half years, the Ironclad Exide Battery will cost £200 and last three years, whilst the iron-nickel battery will cost £400 and last six years. The longer-lived batteries have the advantage of saving the operator considerable worry, as trouble due to the battery nearing the end of its useful life occurs less frequently.

The lead battery class can be divided into the "flat plate" and the "Ironclad Exide" as made by the Chloride Co., the latter having the distinctive feature of the active material of the positive plates being enclosed in hard rubber tubes. In pursuit of light weight the ordinary flat plate has been reduced to about $\frac{1}{8}$ inch in thickness, which is insufficient to withstand the vibration and buckling stresses to which they are subjected, and the battery usually requires washing out after 4000–5000 miles running. Special types of separators are now being manufactured, which it is hoped will altogether prevent the shedding of the active material and obviate the necessity for any washing out throughout the life of the plates.

The spacing of the plates is the minimum that the volume of electrolyte will permit, whilst the specific gravity is kept high, frequently as high as 1,300. The separators are usually of wood ribbed on one side and plain on the one which is next to the negative plate, a thin perforated sheet of ebonite being usually placed next to the positive plate. Celluloid should not be used for separators as it is eventually attacked by the strong acid. The boxes are made of hard rubber with sealed in but removable lids fitted with rubber vent-plugs.

The Ironclad Cell embodies a flat negative plate, but, as previously indicated, it has a special positive which consists of a number of pencils joined top and bottom to a horizontal bar. Each vertical pencil contains a hard lead-core surrounded by the active material, peroxide of lead, which in turn is enclosed by a hard rubber tube having a large number of horizontal slits. These slits allow the electrolyte access to the active material, and yet are so fine as practically to prevent the washing out of the active material. The tubes are provided with two vertical ribs which stiffen them and also act as spacing pieces allowing of the use of plain wood separators. The rubber tubes are elastic to an extent sufficient to allow of the expansion and contraction of the active material during charge and discharge, and being cylindrical are not affected by any liability to buckle. The capacity for taking high rate boosting charges which the "Ironclad" enjoys together with the

Edison Battery has entirely altered the radius of action of the electric battery vehicles. For instance, the vans used by The Hays Wharf Cartage Co., which have a normal radius of about 40 miles, are doing 70 miles per day regularly by reason of their having a mid-day boost of one and a half hours.

APPENDIX II.

Iron-Nickel Cell.

The best known example of the iron-nickel cell is the "Edison," which was primarily designed with the object of eliminating the use of sulphuric acid and substituting a material of greater mechanical strength for the lead. The "Alklum," the manufacture of which is now being undertaken in this country, is of very similar construction. Thousands of couples were tried out by Edison and abandoned in favour of iron and nickel oxide in a solution of caustic potash. The cell brought out in 1901 was the forerunner of the present day one, but was modified in many mechanical details before assuming its final form in 1908. All battery descriptions tend to centre round the positive plate, and the Edison Battery is no exception. Its success is largely due to the fact that it is almost impossible to dislodge the active material.

The positive plate is made up of perforated nickel-plated steel tubes of about $\frac{1}{4}$ inch diameter, which contain alternate thin layers of nickel hydrate and metallic nickel prepared in a finely flaked form. The function of the nickel is purely a conducting one, the nickel hydrate being so poor a conductor that it is necessary to provide as many paths for the current to the steel tube as possible. The steel tubes, which are formed of thin strip steel coiled spirally, are strengthened by eight steel bands placed equidistantly throughout their length. A complete positive plate comprises two rows of fifteen tubes, held in a nickel-plated steel grid by short tongues of steel cut in the grid and forced down by hydraulic pressure. The negative plate is of a form originally used for both elements,

and is composed of a steel grid supporting flat perforated nickel-steel pockets which are filled with finely divided iron-oxide to which has been added a small proportion of mercury to reduce the specific resistance. The pockets are forced into the grid by hydraulic die pressure, which at one and the same time corrugates the pocket, so making it elastic yet rigid, consolidates the active material, and securely fixes the pocket in intimate contact with the grid itself.

The plates have holes at the top which fit snugly over the cross-connecting bolts on which the terminals are forced by pressure. The plates are held at the requisite distance apart by spacing washers, and the whole locked tightly together by nuts on the end. All parts are heavily plated before assembly, very special attention having been paid to the plating process by the Edison Co. to obviate any chance of stripping.

The elements are assembled in a steel can with ebonite insulating strips inserted between the plates and at the bottom and sides. The cover which is provided with a filling opening protected by a gravity valve and holes for the terminal posts is then welded on. The latter are tapered and pass through stuffing-boxes of compressed paper which prevent terminal leakage. The electrolyte is a 21 per cent. solution of caustic potash with a small percentage of lithium hydrate. Great care appears to have been bestowed on all the details, and the cell is mechanically fit to stand up to all the abuse which is likely to be met with in vehicle working. As is to be expected from a consideration of the construction of the Edison battery, its cost is high, and for the same duty is roughly twice the price of an "Ironclad Exide," although on the other hand it is guaranteed to give at least double the life and requires very little attention. The voltage is low, only 1·2 per cell, but the individual cell is light, and the larger number required does not mean an increase in total weight. The internal resistance is high, which is a disadvantage for some classes of service.

Discussion in London, 21st November 1919.

The Chairman (Mr. Mark H. Robinson, *Vice-President*), in proposing a very hearty vote of thanks to the Author for his Paper, said he was sure the members would agree that it raised many points of great interest, and he hoped a good discussion would ensue.

The resolution of thanks was carried by acclamation.

Mr. L. A. Legros, O.B.E., in opening the discussion, said he intended to find a few faults with the Paper, which were faults more of omission than anything else. Reference was made on page 665 to a Report on Road Transport issued some time ago by the Massachusetts Institute of Technology, but the Author did not give full reference to that Report. He hoped the full reference would be given, because a good many of the members, like himself, would prefer to read the original Paper in order to obtain more data than were given in the abstract quoted by the Author. On page 678 the Author just touched on the question of four-wheel drive. The four-wheel drive had had a very big vogue for heavy transport in America, and in parts of this country, where the roads were more than ordinarily hilly, he certainly thought it was a form of transport which was likely to increase rather than to remain stationary.

In the next place he desired to join issue altogether with the Author's views given in the Paper in reference to chain-tractors. The vehicle illustrated in Fig. 22, Plate 22, had almost every conceivable defect that could be put into a chain-tractor. The plates were shown separating so that they could act as nut-crackers; they were shown coming down at a considerable angle to the ground, causing digging, and the return of the chain at the top formed a reverse curve, so that it would require a guide on the outer and dirty side of the plates, which was extremely difficult to arrange. Among other defects the absence of springs was notable. A chain-tractor, which was intended to do otherwise than damage the roads, must be provided with springs or sprung truck-frames, in order to

prevent concentration of the load on parts of the road surface—which was usually far from being an absolute plane. The other chain-track vehicle shown in Fig. 23 was also far from being comparable with ordinary American practice. The clutch-gear was apparently exposed to the weather, and no means were shown of springing the frame from the track so as to keep it in contact with the ground. The last Mark of "tank" that had quite recently been developed was capable of travelling at 17 miles per hour, and that result had been rendered possible by the use of springs which enabled the chain to be pressed down on the road or on the surface of the ground at different points along its length. The use of chain tractors for agricultural purposes was, as the Author pointed out, hampered by the restrictions imposed on the travel of such vehicles on roads. In some counties they were allowed to travel under their own power. He knew of one case, in the south of England, in which a 75 h.p. Holt tractor was allowed to travel over the county roads on its own power instead of being hauled from one farm to another, provided that spuds or grousers were not used on the chains while travelling.

On page 695 the Author gave the results of some experiments that had been made to determine the actual loss of power when no differential was used. The invention of the differential gear dated back very nearly one hundred years, as the members were probably aware, but it was first brought into common use for road vehicles by Starley. The figures which were given in the Paper were, as far as he knew, the first that had been obtained in practice. These measurements were more easy to make with an electric motor than with a petrol or other motor, and they were extremely valuable as showing the loss of power, varying from 7 to 12 per cent., that had been determined by experiment. It must be remembered, moreover, that this loss of power was devoted entirely to wearing out the tyres.

The Author had touched upon arrangements for the collection of goods with a view to their dispatch. As the Author was a railway man, he probably was aware that a very big class of business was done on the Continent in what was called "grouping"

(Mr. L. A. Legros, O.B.E.)
goods. Under that system, in several countries, a collection of goods was made and these were grouped according to destination at certain places. They were then put into closed wagons, which were lead-sealed, so that they could be run through the Customs frontiers of intermediate countries without examination. This obtained particularly in the case of Switzerland, and it was quite probable that some similar system could be adopted with a view to getting over the two great wastes which occurred in motor traction, wastes to which the Author had referred in several parts of his Paper, namely, first the finding of a return load and so saving the dead mileage, and second the time lost in stoppages. In conclusion, he congratulated the Author on the excellent information he had given relating to methods of handling and loading goods on to motor-lorries and trailers.

Mr. Thomas Clarkson said he regretted that he had been asked to speak on the Paper at the present time, because he had not had an opportunity of studying it so carefully as it deserved, and it was quite impossible to assimilate the Paper as it was read in abstract. There were many points in it in which he was sure all the members felt deeply interested. He thought the Author had rightly dealt in the main with the mechanical possibilities of handling the load. The actual application of the power in various types of vehicles had received a great deal of attention, and the aspect upon which engineers would have to focus for some time would no doubt be the possibilities of quick handling of the load, and to supplement that the organizing side would have to see that as far as possible a full load was provided all the time the vehicle was operating on the road. It was clear that, if a vehicle could only carry a full load in one direction and had to make the return journey empty, that dead mileage put up the cost per ton-mile 100 per cent., and a great deal of work would have to be done in order to eliminate that waste. He thought some form of clearing exchanges was inevitable. Whether that should be done by a Government Department or not was a moot question; he was rather inclined to think it would be done better otherwise.

With regard to the various types of propellant, whether steam, petrol, or electric, he would follow the example of the Author and only touch very lightly upon the subject, because the Author had not made it the chief issue in the Paper. He thought all the members would agree that "more water must run under the bridge" before finality was reached in that respect. The subject was still in a state of flux, and much depended upon the changes that took place from time to time in the commercial aspect, that is, the cost of fuel. Before the War petrol was about one-third of its present price, while fuels suitable for external combustion were also very much dearer than they were at that time. It was largely a matter of money. The engineer had to figure out whether it would pay him better to use one thing or another, but he hoped that, with the amount of engineering ability that was now being focussed upon the question, a distinct advance towards a solution would be made in the near future. He could not conclude without expressing his appreciation and thanks to the Author for the many practical suggestions he had made in his Paper.

Dr. H. S. Hele-Shaw, F.R.S. (Member of Council), said the motor-vehicle itself had now reached a high state of perfection, but there were three problems connected with it, as with locomotion generally. These problems were (1) loading, (2) locomotion, and (3) discharge. Of these locomotion had received by far the most attention, and this was not surprising as the solution necessitated the greatest skill and ingenuity on the part of engineers, and had resulted in some really wonderful inventions in mechanical science. It was equally not surprising that the other two problems had been neglected because goods, especially on the scale employed with motor-vehicles, could be handled by manual labour in the same primitive way as from time immemorial. Recently, however, as the previous speaker had remarked, the question of loading and unloading had become a very pressing one. The delay which occurred in the old days of the horse vehicle, when the driver was glad that his horse should have a nosebag on for a couple of hours while the vehicle was being loaded and unloaded, was commercially

(Dr. H. S. Hele-Shaw, F.R.S.)
impossible to-day; and a vehicle representing a large amount of capital could not be allowed to stand idle owing to defective means of loading and discharge.

He was very glad to find that the Author began his Paper by calling attention to the fact that "the methods employed for handling and carrying the goods are in most cases exceedingly crude, very few serious attempts having been made to employ the apparatus already available or to evolve new methods and machines for the saving of time and labour." That was the keynote of the whole Paper, and everyone would agree that it was the case of a good and expensive tool with a most imperfect means of operation. The Author had summarized the progress which had been made and had described the state of affairs that existed at the present time. One of the chief improvements in dealing with goods was the adoption of the principle of the use of a container. That principle had for many years made the handling of traffic across the Channel very different from what it was in the old days. A container with all the luggage in it was quickly lifted from the railway truck and dropped on to the steamer, and instead of the wretched passengers having to wait a couple of hours while the luggage was moved piecemeal, a wait of only a few minutes was necessary.

He noticed that the Author also said on page 662: "Proposals such as have been put forward by Gattie for collecting and delivering miscellaneous parcels and goods traffic have much to commend them theoretically, but, although they do not present any difficulties on the engineering side, they appear to require further consideration from the commercial and operating point of view before any hope can be entertained of practical success." Mr. Gattie was present that evening, and after all the years during which he had been advocating the better handling of goods, he would be gratified to hear from an engineer of the Midland Railway that his scheme did not present any difficulties on the engineering side, especially as in the recent Government inquiry on the Gattie scheme everyone had not gone as far as this. The principle of Mr. Gattie's interesting invention was simply to bring the whole of the goods coming into

London and other cities in containers, then sort them by his track railway, and distribute them on motor-vehicles. What was wanted was system, whether for railway trucks or motor-vehicles.

The Exhibition now being held at the Agricultural Hall, which all engineers interested in the subject should visit, showed what great progress had been made in various directions, such as with the tipping-wagon, which was one way of handling goods better. Hydraulic tippers and all sorts of ingenious arrangements for handling goods in a proper engineering manner were there shown. There were various contrivances for shifting the body of the vehicle. In particular, there was one vehicle which had many different bodies. Under one arrangement it could be used as a funeral hearse and the next day it could be used for carting manure. The members seemed amused at that statement, but he would remark, in passing, there was one way in which the motor-vehicle could be improved, namely, in the way of going smoothly at any required speed however slow the traffic. A man who drove for one of the principal funeral establishments in Manchester told him that the anxiety of his life was trying to keep the motor-vehicle conveying the coffin at a suitable pace and avoid spasmodic rushes in the midst of a walking funeral procession.

An important matter was dealt with by the Author under the head of "barrows" (page 682). When the beautiful electrical platform vehicles carrying large loads behind them, with one man operating them, were first employed on railway stations, everyone realized the immense loss of time and labour that had hitherto been involved in this work; only to-day was there a whole-page advertisement in a leading paper of the Cowan transveyor. Another conveyor of the same kind (which was called in America a jacktruck) made by Hardaker, was illustrated in the Paper, Figs. 40–41, Plate 24. He was not prepared to discuss the relative merits of the two jacktrucks because he knew very little about them, but he had been supplied with a small model of the Cowan transveyor, and he would like to show the members what it did. Instead of dumping down goods with which it was desired to deal, there was a comparatively inexpensive platform with side

(Dr. H. S. Hele-Shaw, F.R.S.)

supports which could stand anywhere. It was possible to have hundreds of such platforms which could be stamped out of steel or made of wood. It carried the load for transfer to the vehicle and it could be lifted up and put bodily on the vehicle. It was not necessary to handle the goods to enable it to be worked. The jacktruck or the transveyor ran on wheels underneath the frame, and when it was underneath all that had to be done was to push the handle down, thus raising the platform with its load off the ground.

In conclusion, he desired to say that he was very glad that the discussion had been directed to this particular aspect of mechanical road traction, namely, dealing with the goods, because one purpose of discussion was to indicate the direction in which progress was urgently needed, and in which members could profitably exert their ingenuity. Thus the concluding portion of the Paper, in which the Author dealt with various problems, might really be summarized under the title of Handling of Goods, and in these days of strikes, the question of saving time and labour by means of labour-saving appliances was a most urgent problem.

Mr. C. W. Stamper said that he had been particularly interested in the subject of motor transport for a good many years, especially in the handling of goods in quantity from and to the motor-vehicle. He had invented a detachable body system or a loading truck upon which the body could be transferred from the lorry complete with its load on to the loading truck and vice versa. That bore out the Author's statement that, if goods were handled in that way or in a similar manner, it was the only way to get a quick means of handling goods from the depot on to the vehicle, and so save the vehicle having to wait for half an hour or one and a half hours to discharge and pick up a load. He knew that in some large companies the average time of the vehicle in the depot worked out at about three-quarters of an hour, and, if the transport of the goods from one to the other could be done in the space of a quarter of an hour, the saving of half an hour meant the gain of about 7*s.* 6*d.* or 10*s.* per hour, according to the cost of the vehicle and the amount that was paid for the labour to work the vehicle.

Mr. A. W. Gattie said there were two aspects of economy to be arrived at by the clearing-house method with which his name was associated. The first one was the rapidity with which a load could be carried in a detachable container, either such as the last speaker had described or such as Dr. Hele-Shaw had mentioned. It was not vital how the container was removed so long as it was removed smoothly and quickly. The South Eastern Railway containers to which Dr. Hele-Shaw had referred had rollers underneath them, and they could be rolled off the truck if that was the intention. But in the case of the railway containers carried to Folkestone, they were not carried on the rollers on the railway truck but stood solid on the railway truck and the rollers did not touch. The rollers, however, came into operation when the containers were lowered into the hold of the vessel. It would therefore be seen that there was not a very great difference between the containers spoken of by Dr. Hele-Shaw and the containers referred to by the last speaker. The great thing was that a container could be removed from a lorry in a matter of a minute or two minutes or three minutes, and that, having been removed, the lorry would then stand in the clearing house and would have a previously-prepared container, containing assorted goods, immediately loaded on to it, and it would again depart on its journey of distribution. In that respect there was a very great gain of time. He was informed recently by Messrs. Cook, Son, and Company that at the present moment it was not an uncommon thing for their vehicles to be detained at Smithfield for five or six hours, which was a very great loss of time. He took their word for it that they were not exaggerating. The London Parcels Delivery Company, Carter Paterson, and Pickford all said there was a considerable delay at the depot in exchanging the incoming load for the outgoing load, and that was a serious thing when the value of the machines which were being detained was taken into consideration. That delay would not take place under clearing-house conditions.

He now came to another economy which would, he thought. surprise the members. He did not think he would have known about that economy—at any rate, he would not have known it so

(Mr. A. W. Gattie.)
vividly as he did—if it had not been that in his early days he was an official of the Bank of England. The clearing-house principle was instilled in his mind by his daily drudgery in the clearing-house. He was not old enough to remember the beginning of the bankers' clearing-house—that was before his time—but his grandfather knew a great deal about it. In those early days there were 40 bankers, each of whom called on the others. Each banker called on the other 39 in an all-round transaction, but now-a-days each clerk carried a satchel-load of cheques which he brought to the clearing-house and, having got there, he distributed them and took back to his bank the enormous quantity of cheques which had arrived from the various other banks. In the old days when each banker called on the other 39 it meant 1,560 visits, 1,560 little walks, 1,560 opening of swing doors and closing them again. But with the advent of the clearing-house the 40 bankers called on one clearing-house, which meant 40 visits instead of 1,560, a saving of 97 per cent. If that was important in the case of a clerk with a satchel containing a small parcel of cheques, it was far more important in the case of an expensive motor-lorry containing some tons of goods.

In one of his peregrinations he took a walk down Friday Street with an ex-Lord Mayor of London whom he was trying to convert, and did convert. The ex-Lord Mayor said to him, after they had walked to the other end of the street, "I am converted, but you won't be able to convert the other Aldermen so easily as you have converted me." They there saw in a narrow street, about 9 feet wide except in a few places, a number of horses with their nosebags on and the carmen smoking their pipes. They seemed to be very pleased with themselves; there was very little being done, because all the carts could not get to the place to which they wanted to go, and the stuff had to be pulled in a hand-truck along a narrow pavement from the place at which the cart had pulled up to the particular warehouse to which the goods were consigned. If, however, clearing-house methods were adopted, one motor-lorry at a time would be detailed to that particular street, and it would be able immediately to reach the door of anybody and everybody. It might happen sometimes that the driver would have to unload

the whole of his container at one place, and in such cases it would be a very good thing to have some lifting or sliding device by means of which the whole load could be transferred to the warehouse. There were various kinds of cranes which did that work, more particularly in the printing trade. The great advantage of such a system was that the vehicle mileage would be reduced enormously, because a man starting from a centre could take all the goods for that particular street, and therefore, instead of having to traverse twenty streets in getting rid of his load, he would be able to discharge the whole of his load in one street much more rapidly. He could then turn round and be in the best possible position for making a collection of goods and returning to the clearing-house, from which the goods could be despatched to all parts of the world. That was the other and the greater economy of the two. The carriage of the whole of the goods of London, which now occupied 100,000 vehicles, could be done in 5,000 vehicles. He had given very minute details of the scheme at more than one of his lectures, and if any member of the Institution desired to have those details he need only ask, and a copy of his speech at the Royal Automobile Club or at the Royal Society of Arts would be sent to him with very great pleasure.

Mr. William H. Patchell (Member of Council) said that Dr. Hele-Shaw had just mentioned the use to which a hearse could be put. He knew as a fact that some friends of his wished to have a large model sent from Glasgow to Edinburgh, and as, owing to the way in which the railways were being worked at present, passenger trains and goods trains were entirely out of the question, the model was conveyed from Glasgow to Edinburgh in a motor-hearse.

Mr. Edward Batten said he thought that, if on page 685 the Author gave some indication of the relative prices of the different fuels referred to, it would make the Paper of more permanent value, because the members would then be able to make their own calculations in regard to Fig. 45. He thought everyone present

(Mr. Edward Batten.)

must have been abundantly convinced that, in regard to the engineering side of the problem it was now in very able hands, that competition was so keen in regard to different kinds of vehicles, and also in regard to the different individual types, that there was no doubt the question of road transport as regards its mechanical side was in such hands that it would continue to develop, and that the general emulation in regard to different design and construction would evolve the best type of ultimate efficiency.

Mr. Legros had rather taken exception to the Author's contentions in regard to four-wheel drivers and "caterpillars." It must be borne in mind, however, that the question of road transport was being dealt with, and in his opinion anyone who had had an extended experience with commercial vehicles in road transport would not want to adopt four-wheel drivers. He might need to adopt four-wheel drivers for certain special purposes, but he would adopt them only if constrained to do so, because the extra complication, at any rate in an internal-combustion type, which was produced was not a thing to be desired. If drivers of the electric type were used, he thought conditions were about equal, but what he had said certainly applied to the petrol type. With regard to the "caterpillar" type, who amongst the members who was organizing or hoped to organize for road transport was willingly going to adopt anything in the shape of that type, although he might be compelled to use it for certain purposes? For instance, he had an inquiry a few days ago from a large forage merchant who wanted to know if it were possible to fetch his hay from the stacks in the fields. He replied that it was impossible to do so except with a "caterpillar," and that if he wished to adopt mechanical transport for his hay he must get the farmers from whom he bought it to stack it on the side of the road, so that it could easily be picked up; otherwise it could not be removed by mechanical transport except with the aid of "caterpillars."

Another point which occurred to his mind in connexion with Dr. Hele-Shaw's remarks (page 705), was the conditions which were likely to obtain in the future. There was one thing which

road transport could do which no other form of transport could accomplish, namely, it would enable England to be settled. It had probably occurred to members, as it had to himself, that it was possible to travel many miles through the countryside of England, which was supposed to be so thickly populated and so efficiently organized, both in regard to agriculture and otherwise, and see what was practically a desert. One did not see any live stock or cornfields.

Another point he wished to urge was that there was no bad land near towns. If one went with a farmer, who had a 300- or 400-acre farm, through his fields and told him that one did not know how he lived off these acres in their neglected condition, the farmer replied that it was because the land was bad, that it was barren. But he appealed to any member present to say whether it was not the fact that no bad land was found near a town, from which he inferred that if the people could be brought to the land there would not be any bad land in England, and it was transport which would enable that to be done.

The statement was made in the House of Commons on the previous evening that the railways were to be "rivers of electricity." Personally he did not think that was the place where the rivers should run. He thought the rivers of electricity should run along the main roads, because in going from town to town on the railway practically nothing was to be seen, but, if one went from town to town on the main roads, villages all along the roads came into view. He maintained that, if there were light and power along the main roads, the development of village and family life and of manufacture under better conditions would be increased in a manner in which it would never be whilst such facilities were confined to the railways. It was also necessary to improve the environment of vehicles by making good main roads. If any of the members were concerned with the transport question during the recent railway strike, they would know the difficulties that were experienced owing to the bad lighting of the roads. Dynamos were used in some cases on the lorry for that purpose, and on a stretch of one mile there were twenty or more dynamos, which did not seem to him to be efficient engineering. In his opinion it was essential

(Mr. Edward Batten.)
that the main roads should be lit by night, in order that the streams of traffic might proceed safely, and if electricity were installed along the main roads he thought it would be in the place where it was wanted. Another advantage of such a system would be that very many electrical vehicles would be able to pick up current *en route*. If they were battery-charged they could charge their batteries up at the same time on the main road. He knew that what he was saying was very much in the air, but England would not be properly populated and settled until the roads were made better, and were made the channel of communication of power and of light.

Professor W. E. Dalby, F.R.S. (Member of Council) said there was one point of technical interest in the Paper on page 695 to which he wished to refer. The matter had already been mentioned by Mr. Legros. On that page some definite figures were set out giving the comparison between the power required to drive a motor-vehicle, first with the differential locked, and secondly with the differential free to work normally. It would add very much to the interest of the Paper if a few particulars were given of the kind of road over which the vehicle was run. The difference of power in two such experiments could be varied indefinitely if the car were run in circles of varying diameter. If it were possible to add a rough plan of the kind of road over which the test was made, giving some idea of how many curves there were in it, and if at the same time a note were added in regard to the road surface, it would add very much value to the figures which were given in the Table at the bottom of page 695.

Mr. John Abbott said there were two points he would like to refer to, which had been mentioned in the course of the discussion. One speaker had referred to the question of moving hay from a field. Some little while ago he saw a Pedrail Tractor which struck him as being built on a very sound and workmanlike principle. It got over a large number of the difficulties that were experienced with a "caterpillar," in which grit was much more likely to work

in between the many joints than on the Pedrail, the joints of which were carried much higher above the ground level. He hoped that some member who was more familiar with the Pedrail than he was himself would give further information on that subject.

The second point to which he wished to refer was the fear that had been expressed in regard to the adoption of four-wheel drives. He visited the Shipping Exhibition a few weeks ago, and was there struck by the possibilities of the Hele-Shaw pump. He thought the problems of the four-wheel drive would be very well met by using this method of transmission, and many of the mechanical difficulties would disappear. The conveyance of the oil driving each wheel could be made by flexible tubes if necessary, presenting no serious difficulties, and doing away with much existing fear against adopting four-wheel drives because of mechanical difficulties hitherto experienced.

Mr. G. Mackenzie Junner said he joined in the discussion mainly because of what the Author had written on the subject of traffic congestion in large towns. He suggested in that connexion that there should be a clearing house or houses for passengers. Much of the traffic congestion in the centre of London was caused by passenger vehicles which ran out to the suburbs and dropped perhaps three-quarters of their full complement of passengers at about half the distance of their total journey. When they arrived towards the end of the journey they were left with perhaps two or three passengers, and a vehicle which was intended to carry a considerable number was then running almost light. If clearing houses were established at different points away from the centre of the town, they could be fed by full vehicles, and those vehicles could make repeated journeys backwards and forwards between the heart of the city and the clearing houses. Other passenger vehicles could then empty the clearing houses. Such a system would prevent to a great extent the use of an expensive vehicle for few passengers.

In regard to tipping gears, with reference to which, however,

(Mr. G. Mackenzie Junner.)
the Author did not give any figures, from a rough calculation which he (the speaker) had made, he estimated that about 72,000 ft.-lb. of work were expended in merely tipping the load, and a man was expected to tip the load in two minutes. It seemed to him that a good deal of unnecessary labour was expended in lifting the load. Certain designers shifted the whole load backwards on runners, and then tipped it when it was on the balance, which seemed to him a much better arrangement.

Mr. S. G. Williams said that he had spent a considerable amount of time in the Midlands, and as a result the importance of road transport was closely brought home to him. When that district commenced engineering activities about a hundred years ago, it had to trust entirely to canals for its transport. Those canals had been the artery of the whole of the industrial system, and works were to be seen cohering, as it were, to the banks of the canals. Consequently the railway system in that part of the country, as many of the members knew, was very poor. In view of the importance of obtaining new districts in which to erect works, great engineering works were springing up outside those closely concentrated areas, and in some cases in the middle of fields with very small railway facilities. They were therefore driven to look to the roads for their means of obtaining raw materials and sending out their finished commodities. That brought him to the point that the roads should be considered as parallel in importance to the vehicles that ran upon them; and anyone driving over the roads of this country would notice the deterioration that had taken place in their surface during the very active period of the War. He thought, therefore, the Paper should not pass without some mention of the necessity of bringing the roads up to as efficient a standard as the vehicles themselves. The roads had not met with very much improvement. He believed the Romans designed them; men like Telford put surfaces upon them, and General Maybury had given the billiard-table surface which made the roads of this country noted; but those asphalt surfaces were not sufficient to stand the wear and tear of fast-running motor

vehicles. Three- and four-ton lorries raced along the main roads at 15, 20 or 25 miles an hour. It was not legal, but it was done, and it was possible to see vehicles racing along at that pace on any main road, with the result that the down gradients quickly became full of pot-holes and subsequently axle and other mechanical troubles set in. The worst accident that could happen to a lorry was to have a broken axle.

He desired to mention the work that had been done in regard to the nature of steels during the last two or three years, and to point out the necessity of using very high class steels, preferably nickel-chrome, for vital parts such as axles. It might be wise to depart from the solid-axle type and use a hollow section of large diameter in order to obtain the greater strength and resilience which were wanted, rather than actual mass strength. In conclusion, he wished to draw attention to the necessity for the heat-treatment of axles. He believed that the Foden Steam Wagon Company treated their axles by means of a furnace in which non-oxidizing conditions were obtained by gas which surrounded the work. The axles were oil-hardened, and tempered under conditions which prevented scaling. The axles could then be replaced after a little polishing, which was a very cheap type of insurance against failure on the road.

The Chairman, before calling on the Author to reply, said that he had listened to the Paper with a great deal of interest, as it put before the members a field in which the British engineer ought to be employed much more largely than he was at present, and where there was every hope of increased work for them in the future. The engineer had almost ousted the horse; at any rate, he had gone a long way towards doing so; but he had not at present ousted the people who collaborated with the horse and carried on the traffic in the dawdling style which that animal, not through his own fault, was accustomed to. It was evident that the engineer and the designer should be employed more than at present in the important work of handling goods which were already moved speedily and economically when they were allowed to move at all.

(Mr. Mark H. Robinson.)

The discussion seemed to have largely centred round "containers," but he hoped the engineers who took up that subject and developed it would not lose sight of the small articles. Dr. Hele-Shaw had referred to the big container in which the luggage was swung from the railway truck into the hold of the steamer, thereby much improving the cross-channel traffic, but it must be remembered that in that case the container carried articles for one destination only, the port on the other side of the Channel. He hoped that some system of motor traffic would be worked out for carrying articles economically to many destinations in the same vehicle, and the needs of the small article should be considered as well as the large ones. More than fifty years ago he had made the drawings of a steam-lorry for the purpose of delivering coal, and for other kinds of traffic, and he then put in what was more or less a novelty at that time—a crane mounted upon the vehicle itself, which could lift out one article without greatly disturbing others, and he thought there were many cases in which that simple arrangement did all that could be asked for. They had had a useful, because suggestive, Paper, and they would gladly hear the Author's further remarks.

Mr. C. G. Conradi, in reply, desired in the first place to thank the members very heartily for the manner in which they had received the Paper. He concluded his Paper by thanking some of his friends who had been good enough to place information at his disposal, and he desired to take the present opportunity of thanking his wife for preparing the Paper to a large extent. Unfortunately it had to be prepared under rather strenuous circumstances, and it was due to her that he should make a public avowal of what she did in that respect.

Mr. Legros had taken him to task over the four-wheel drive, and also over the tractor, but he thought he was quite right in abiding by what he said in the Paper. He said, when dealing with the four-wheel drive (page 678): "It is very questionable, however, whether the conditions in this country are ever severe enough to warrant the extra expense in first cost and

maintenance occasioned by the adoption of this design of vehicle, although it has much to recommend it in the case of heavy tractors." Engineers all desired to improve motor traction as well as other forms of traction. No doubt the roads would now be repaired very rapidly, and, with the improvement of roads, he could see very little need for the four-wheel drive. The additional complication involved must mean quite a substantial increase in the maintenance costs. It would be noted that he said with regard to the tractor: "Vehicles constructed on the caterpillar or track-laying system are not likely to come into use for general purposes, and they will no doubt be restricted to work on bad roads and rough land or for military purposes." He thought Mr. Legros was really in agreement with him on that point. The multiplicity of small joints in the best design of track-laying machine was bound to put it out of court in commercial work, and it was necessary therefore to look at things from the point of view of whether they were remunerative or not.

Mr. Clarkson had questioned the advisability of organizing the road for transport and of freight exchanges by a Government Department. He (the Author) meant the note in the Paper on this point to imply that it was only the organization that might be carried out by such a Department—not the actual working, which no doubt ought to be left in the hands of commercial men. There appeared, however, to be only one way of bringing all those people together quickly, and that was by means of a Government Department.

Mr. Gattie had emphasized the great need which he (the Author) had tried to point out existed for making use of all classes of labour-saving devices. The only point perhaps on which he would join issue with Mr. Gattie was on the more detailed arrangements, and more particularly perhaps outside of the clearing house, if such came into operation.

With regard to Mr. Batten's remarks (page 711), the value of the fuels taken in making up the diagram, Fig. 45 (page 685) were: current, $1\frac{1}{2}d.$; petrol, $2s.\ 6d.$; coke, $30s.$ The four-wheel drive, if it were required, as Mr. Batten pointed out, was very

(Mr. C. G. Conradi.)
readily obtained by means of electric vehicles. There was quite a number of designs which could be operated in that manner, for instance, the Cedes, the Commercial Truck, and the Coupled Gear, also Mossay's system, whilst the Fram could be adapted to work in that way as well. Going further still in the same direction, we might use petrol-electric road trains, which were practicable and which no doubt in the near future would be made possible by alteration of the law. The question of streams of electric current being available would no doubt come within the realms of possibility in the near future, but he thought if Mr. Batten studied the map he would see that the principal roads, canals, and railways, ran more or less parallel, so that if the electric supply were taken down the railways it would certainly not be far away from the main road arteries.

Professor Dalby (page 714) had referred to the tests on the differential and asked for further information as to the conditions. These tests were carried out over the same piece of road by the same driver, and as nearly as possible under exactly the same weather conditions. He would refer Professor Dalby for further information to the report contained in *The Electrician* of 31 August 1917, but, as far as he could recollect, he believed the number of turns was equal, that is, twenty-one to the right and twenty-one to the left. The tests were carried out in dry weather with practically no wind, and the greatest proportion of the route was tarred macadam with a very good surface. As a matter of fact, he did try, after the series of tests was finished, to turn round in a circle a good many times, with the result that he broke the live axle.

The problem that Mr. Junner had raised (page 715) might, he thought, be referred to Mr. Gattie, who would probably now have to get out a series of passenger containers. The question relating to power and the time of tipping loads was not a very vital one, as the time taken for the operation was extremely short. The work usually took an average of one-horse power and occupied probably three-quarters of a minute. The hand-operated gear which he referred to was one in which the load was run out to the rear of the vehicle until it was practically balanced, and it was then allowed

to tip under the control of toggle-levers. One man could quite easily operate that gear and tip a load of 5 tons in two minutes.

Discussion in Manchester on Thursday, 27th November 1919.

The Chairman (Mr. Daniel Adamson, *Member of Council*) said that in the early part of the Paper reference was made to Mr. Gattie. They had had the pleasure of hearing an Address in that room from Mr. Gattie on the subject a few months ago; since then Mr. Gattie had been in Manchester on one or two occasions and the meetings had been so crowded that he was to come again.

Mention was also made in the Paper of the work done by the Manchester Chamber of Commerce. The members would be interested to know that Mr. Fine, a gentleman connected with that Department, was present that evening and might make a few remarks in the course of the discussion. There was a reference (page 665) to a member of the Engineers' Club, who was also present, Mr. L. Brookman, who had in recent times entered into debates on similar subjects.

The essential point of the Paper was that if one had an expensive mechanical contrivance for moving goods quickly, he must take care to make efficient use of it, and the whole argument revolved round the problem how to carry out the details for that efficient use. Mr. Conradi mentioned several appliances which had come to his notice during his extensive experience in this particular direction. It was to be hoped that in the course of the evening some of the members would be able to throw more light upon the subjects which Mr. Conradi put forward.

On reading the Paper a small detail occurred to him as to whether brakes were necessary for trailers. It seemed to him that at the ten miles or so per hour that Mr. Conradi proposed to run, it would certainly be desirable to have brakes.

(Mr. Daniel Adamson.)

A notable feature of the Paper, which no doubt would give rise to discussion, was the favourable mention of electric vehicles. Most engineers were inclined to look askance at them in view of the troubles which had been experienced in the past with storage batteries, but those difficulties might now have been overcome. The Author had had considerable experience in the distribution of goods by road, and he had summarized some of the results of that experience in this Paper.

Mr. L. Brookman said he admired the comprehensive way in which the Author had dealt with so wide a subject. He felt gratified that his own views were largely corroborated by the experience of the Author, who, moreover, paid him the compliment of quoting from his Glasgow Paper on "Self-propelled Electric Vehicles."

Referring to the bottom line on page 665, he would like to point out that there was considerable divergence between the relative positions of the curves now and what would be found if one went back three years. Since his Glasgow Paper was delivered horse-traction costs had risen 100 per cent., whereas the costs for electric-traction had only risen $33\frac{1}{3}$ per cent. There was practically no horse-service, worthy of being dignified as service, which could not be done cheaper by electric-traction now. Sometimes a deterring factor to changing over to electric-traction was that there was little garage accommodation, and the men knew nothing about storage batteries or motors, but that difficulty was being overcome now by the establishment in many large industrial centres of service garages. Any subscriber to such an organization would merely have to buy his vehicle, and the garage would keep it on the road. The vehicle was cleaned and charged, and the tyres and batteries were periodically renewed. All that was done for a given figure, a definite rate per mile, so that the user knew his position absolutely as regarded his transport costs and had no worry at all with the vehicle.

There came another question where a man said, "I should like to buy one, but it is the capital outlay that prevents me. I do not

care to take the money out of my business." That objection was met in this way, that the service garage instead of charging him, say, 2*s*. per mile, would charge him 3*s*. At the end of three years the vehicle would belong to him, and the rate was then reduced to 2*s*. per mile. That was a very comprehensive way of dealing with the problem.

These service garages in various centres were linked up together ultimately so that a man could go from Manchester to (say) Preston, deliver his vehicle, get it charged, leave it there for the night, and go on next day.

Coming to the point of the service reliability, which was referred to on page 689, the figure of 95 per cent. for electric vehicles, which he gave in his Glasgow Paper, was derived from actual statistics; he was most anxious that this 95 per cent. should be a covering figure for conditions, good, bad, and indifferent, in all parts of the country, and not only for a limited period of years, but for twelve or fifteen years. He was quite prepared to accept Mr. Conradi's correction of 97 per cent; he had himself known 99 per cent, but he really preferred to keep to 95. What he wanted particularly to dwell upon was the difficulty of computing what the service loss meant to an industrial concern. He would take the case of materials required for a contract which had been taken under penalty, or a shipment which had to be delivered to a steamer. There the fact of a vehicle not being available at that particular time, being in hospital, might mean £100 a day or any sum they liked to name. It would be difficult to compute. Therefore, the smaller the loss on service efficiency the better.

On the important question of the selection of batteries for any particular vehicle, the Author gave no lead, but like a wise man was waiting until the actual service conditions had been revealed to him. The choice lay between the lead-acid accumulators, among which the "Ironclad" figured largely, and the nickel alkaline cells, of which the Edison was one of the best known exponents. Broadly speaking, the characteristics of the lead-acid cells lent themselves best for heavy work in hilly districts, and in Yorkshire for a number of years now they had given a very good account of

(Mr. L. Brookman.)
themselves. When they came to the lighter kinds of work in level districts and on hard roads, both types of batteries had claims, and the decision on the question of their adoption would be influenced by the actual running costs, other things being equal, of course. As electric vehicles were free from fire risks they could be taken right into the warehouse, run on to the elevator, and taken up to any floor to be packed there, then run down again, and ready for the road and delivery to customers. It saved an enormous amount of handling and also breakages. Again, with power on board for lighting, for self-starting, for hoisting and for traction, they had the advantage with the electrical machine, especially for night work, if night delivery were going to be adopted, in conjunction with insistence on better loading and unloading facilities, approaches to loading platforms and "pull-throughs," instead of the present dead-ends. All these were things which should be taken care of by Traffic Boards, and he believed these would come to pass, so as to speed up locomotion and quicken passenger circulation. All main thoroughfares were very badly congested now. What the condition would be when the expected boom in trade came to pass no one knew. They could not wait to have streets widened and new avenues cut through to contain the enormous traffic which would certainly be on the roads; the facilities at their disposal now must be vastly and immediately extended, and that could only be done if all members of the community would pull together and show their good will.

In conclusion he would like to comment upon the driver's cab in Fig. 36 (page 681). In most of these vehicles the driver was so much exposed that in winter he got thoroughly chilled; in the electric-motor machine one could take advantage of the grid resistance which could be placed somewhere near his feet so as to keep the man warm. It was well worth looking after the driver because he was responsible for the condition of the vehicle, and if he were cold and miserable he would not give it the same attention.

Mr. W. J. Walker said that the characteristic vehicles to which the Author referred contained one very interesting type, the so-

called petrol-electric vehicle, which was stated to be designed for getting over the lack of flexibility so far inherent in the present design of petrol-motor. This type of vehicle, when fitted with batteries for reserve power purposes, certainly appeared to have very decided advantages. He was sorry, however, that the Author had confined himself to references to existing types; after all, the alcohol-electric system appeared to him to be one which, if given a fair chance of development by say the partial if not the total abolition of the Excise Duty on undrinkable spirits, would leave no doubt as to the superiority of the internal-combustion motor as the prime mover, in conjunction with the electric motor. This question had lately been receiving a good deal of attention from the various Engineering Societies, and it was perhaps not too much to hope that some headway would be made soon in developing that means of propulsion.

At the top of page 664 the Author emphasized the question of "lost" or "standing" time. Then he said, "The motor-truck is a time saver; it will carry the same or a greater load much more quickly than horses, but *it is only a time-saver when moving.*" That last clause, which was in italics, appeared to him to be an axiom which applied to all types of vehicles, whether they were animal drawn or whether they were mechanically propelled. The real underlying law appeared to be this: *The greater the speed of the vehicle the greater must be the efficiency of the loading and unloading operations, if the efficiency of the system as a whole was to be maintained.* That appeared to him to cover all cases. Of course, he had not the practical experience in the data which he expected the Author would have on the question of road traction appliances, and so on, but he based the whole thing on three ratios. Suppose they took two vehicles, one of which had a higher speed than the other—say twice the speed, the ratios which he had based his analysis upon were, first, the ratio of the speed of the one vehicle—the higher-speed vehicle—to the speed of the other, which he called x. The other ratios were the ratio of the standing time to the travelling time denoted by t, and the ratio of the capital and maintenance cost of the higher-speed vehicle to the capital and maintenance cost

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of the lower-speed vehicle denoted by c. Those seemed to be the three deciding ratios in the matter, and the expression giving the relation between these and the overall economic efficiency was:— $(1-t)\,\frac{x}{c}+\frac{t}{c}$. He had worked out three cases. If they assumed the higher-speed vehicle to have a speed twice that of the lower-speed vehicle, the capital and maintenance cost of the higher-speed vehicle being say 1·5 times that of the lower, and if they assumed there was no lost time, that is, that the whole time was travelling time, which was an extreme case—the economic value of the higher-speed machine was 1·33 relative to that of the lower-speed machine; that is to say it had 33 per cent advantage. If the standing time were half the total time, the relative economic efficiency of the higher-speed vehicle worked out at unity; that is to say there did not appear to be any advantage in either one or the other machine. If the standing time were three quarters of the total time, the relative efficiency of the higher-speed vehicle worked out at 0·67; that is to say, the lower-speed vehicle appeared to be the advantageous one economically.

The Chairman remarked that if anyone present could say anything about the probable cost of the production of alcohol, it would be useful as supplementing Mr. Walker's remarks, because it all depended on whether alcohol could be produced at a price comparable with the petrol now being used. He then invited Mr. Stone to give some account of transport conditions abroad.

Mr. F. Stone said that undoubtedly mechanical transport would supersede horse transport. With regard to transport abroad, motor traffic was not regarded as a competitor with railway traffic but as a feeder in all parts of the country. What he was chiefly interested in was "caterpillar" traction, because in many countries the roads were of a character which would not allow much pressure on them, and he thought the future of motor transport in foreign countries depended on the production of a tractor or something which would carry a fair load with a very

light pressure not exceeding say 20 lb. per square inch. There were many roads in England that would stand many times that pressure, but he thought if one of these tractors could be devised to give a pressure not exceeding 20 lb. there would be a good future for it.

Up to the present they had had very inefficient electrical vehicles which had never been regarded as competitors with petrol-driven ones, but he certainly thought the future lay with the electrical vehicle. He took the trouble some time ago to work out the thermal efficiency of a modern motor-bicycle, and he was really astounded to find it was only about 5 per cent. In steam-vehicles it was very rarely more than about 10 per cent. When they got figures of that description it caused them to think. He thought that eventually petrol would be produced synthetically. He was a great believer in the electric vehicle, but the trouble was in getting the electricity initially. Some often gave 90 per cent efficiency, but unfortunately they had only about 10 per cent thermal efficiency in the accumulator to start with, so they were limited to 10 per cent at the commencement.

Mr. D. S. Paxton said that the portion of the Paper which was of particular interest to him was that dealing with methods of avoiding terminal delays by loading and unloading devices, interchangeable bodies, and so on. He thought that those who had to consider transport problems would find the Paper of great value for reference purposes. Reference was made (page 693) to the ease with which tests could be carried out when using electric vehicles. The same thing applied to the keeping of records of the running costs, and this was one of the great arguments in favour of employing electric vehicles. Nevertheless, it was worth while, even when dealing with steam and petrol vehicles, to take the extra amount of trouble entailed in keeping as accurate a record as one could, because by doing so the engineer could put his finger quickly on any mechanical weakness that developed and it could be corrected at an early stage.

With regard to the question of trailers, the Author suggested

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(page 675) that their use in congested areas should be confined to night work. That was very good as an ideal, but unfortunately he had found that usually trailers were particularly used in congested areas; in Liverpool, for instance, they were used more than anywhere else in the country probably, in connexion with the dock traffic, the reason being that there was so much time wasted in getting a place in the queue to carry goods away from the ship that one must take as large a tonnage at one time as possible to make the mechanical vehicle pay at all. For that reason trailers were used, in conjunction with wagons with especially long platforms, and restrictions as to speeds and axle-weights were not very strictly observed.

The Chairman had made a remark that mechanical engineers looked askance at electric vehicles. This attitude was a relic of by-gone days. Fifteen or eighteen years ago there were very considerable disappointments in the use of batteries for electric traction, but that had now been entirely overcome. During the last five years in this country, and during the last eight or ten years in the United States, electric vehicles had come into very successful use indeed, and the average life of the best class of lead battery on traction work was anything from three years upwards. Of course in considering whether a vehicle was going to pay on any service, in the first place one took the estimated life of the various parts as a basis for depreciation. For instance, the life of a chassis might be taken as ten years; it would probably last fifteen, but one might take it as ten and write the cost down 10 per cent. per annum. The battery should be considered separately, and depreciated on a basis according to the service. By doing that, one could show where an electric vehicle would be an economical proposition. Other types of batteries more expensive than the lead-acid combination were selected in some cases, and though they cost more, they would last longer, so that there was a relative equality taking the total overall costs. It was found in actual practice that where these vehicles were used for properly organized short distance work, they invariably proved economical. The main consideration to ensure success was to diminish the standing

time and speed up the loading and unloading. By doing that, one could obtain the best results.

Mr. EDWARD W. ALLEN said he had been much interested by the Author's observations in regard to different types of motor-trucks, especially in regard to time lost in loading and unloading. He was hoping they would hear more about the movement of heavy loads over short distances by means of tractors, for instance, in the case of a large works within a comparatively short distance of the railway station. He had not heard much in regard to the use of tractors for that purpose, but he was interested just now in the question as to whether tractors could not be used more economically than horses, say for a distance of a mile between the railway station and the works.

The point on which he hoped to get more information than he had yet done, was as to an economical and speedy means of detaching and attaching trailers from and to motors. In the use of a tractor, they wanted to keep the machine constantly going. The load was brought up to the works, which might be fairly wide-spread, and they wanted some means by which they could rapidly detach the trailer and attach a horse for the purpose of taking the trailer to different parts of the works. At the same time at the railway station one might wish to load up that trailer, to bring it to a central point and rapidly attach it to a tractor for the purpose of moving the load. This was a case where loads were continuous both ways. He had thought a great deal about it and the conclusions he had come to were very similar to those expressed by the Author that in motor traction the time was lost in the standing time, namely, in the time taken in loading and unloading. So far he had not heard very much of the use of suitable means of moving rapidly the trailers to and from different departments of the works. He was under the impression that considerable attention had been given to details of that description and that they might have heard something about good and speedy methods of attaching and detaching trailers to and from tractors, and as to how tractors used in that connexion compared with the use of steam and electric

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wagons. If the Author could offer any information on that point he was sure it would be of value.

Mr. NATHAN FINE said that on looking at Fig. 8, Plate 19, he was particularly struck by the load on the demountable body in the course of transmission from the ground in two and a quarter minutes. If some such arrangement as that could be adopted at the Liverpool and Manchester Docks it would be a wonderful time-saver. It was no uncommon thing now for a motor-lorry to wait perhaps half a day, probably a whole day, for its load. One must consider the fact that the working day consisted of eight hours, and if a man had to go to the Liverpool Docks and wait five or six hours for his load on account of the long queue of vehicles in front of him, and probably his turn came about half-past four, the dockers would often say that it was too late, and then he had to go away and come back the next day. The whole day was thus wasted. The demountable body would save a great deal of time, and it would probably halve the present haulage cost.

The Author had referred very kindly to the work done by the Manchester Chamber of Commerce of which he had been the manager for two years. That was, he supposed, of some little help during the War; it provided return loads and was of much service in that way. But the good it did was nothing to what could be done by such devices as those described by the Author, if there were only some appliance so that the loading and unloading could be done quickly. He was often asked his opinion of the relative values of petrol and steam. His reply would be that petrol haulage was very quick, but it depended on the nature of work to be done. Petro haulage lost its virtue when it got to the docks, because of the delay caused by having to wait its turn, and it could not get though the work as the ordinary steam-machine would do.

One of the previous speakers referred to the comfort of the drivers of electric vehicles. He had often wondered how the drivers of steam-wagons managed, say, on a bitterly cold day when wind, sleet and rain were blowing in. They had no comfort at all; they were absolutely exposed to all the elements, and he wondered

how they managed to endure it. He had seen them come into his office drenched through to the skin so that they were not fit to go on working; but they were anxious to get back, and did not care whether they had a return load or not. If the electric vehicle could be so constructed that in time it could do long trips such as from Manchester to Liverpool, and could run 60 or 70 miles without being recharged, there was undoubtedly a great future for it, but at present it was cut out by the steam-wagon.

The Author commenced by making comparisons between haulage by canal, by railway, and by road. The war and the railway strike had clearly demonstrated to everybody the possibilities of motor transport. Some people said it was only in its infancy, but he maintained that it was not in its infancy. In a couple of years when, perhaps, Mr. Conradi's devices for loading and unloading would have really been established, the trouble of motor haulage would be halved. When one considered that an expensive machine worth £1,200 or £1,500 spent probably half its time waiting for its load, it was high time some such devices as those Mr. Conradi had referred to were insisted upon, so that the cost of haulage might be brought down for the good of the community.

He thought that the haulage contractors would be very much obliged to the Author and the other people who were giving some time and thought in helping them to get over the difficulties of terminal delay. The Author discouraged the use of trailers, but, as one of the previous speakers mentioned, at the Liverpool Docks it was a great success. If one had to wait, it was the same to wait with a 10-ton outfit as with a 4-ton outfit.

Mr. C. G. Conradi said he wished to thank them for the very kind way in which they had received the Paper which, he might say, had had to be prepared under rather strenuous circumstances, and was not just in the form in which he would have liked to present it. With regard to the Chairman's remarks about brakes on trailers (page 721), these of course were already required by law and the arrangements in existence were fairly satisfactory. It was necessary for the trailer to be independently braked either by a

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person riding on it or to make the brakes capable of operation by the driver.

He was much interested in Mr. Brookman's remarks on horse traffic (page 722), and noted that he considered that the horse would be absolutely eliminated by the electric vehicle. No doubt that was very largely true, but at the same time there were many jobs where only one horse was in use. In many such cases an electric vehicle or any motor-vehicle could not be justified, although he had a case in mind where single horses had been dispensed with successfully. This was done by building a cheap type of motor-vehicle just capable of doing the work satisfactorily. It carried 15 cwt., and was capable of a maximum speed of 15 miles per hour; and, although there was nothing much to show in the way of savings, these vehicles displaced the horses and made the fleet working the depot more homogeneous.

His figures for reliability had been referred to, and he would say that in a large fleet with which he was recently connected—very nearly 100 vehicles—each year for a period of perhaps five years quite a number of those vehicles lost not one day, and it was within the range of possibility to work "Electrics" 365 days a year if need be, although he did not agree that that was a good thing to do. What he rather favoured was stopping the vehicles regularly for examination, say two days per quarter—he was speaking now of electric vehicles—stopping them voluntarily, and thereby cutting out the involuntary stops, a procedure which in his opinion would result in a reduction in days out of service of 60 per cent. He also agreed with Mr. Brookman as regards making the driver comfortable, and from the commercial point of view it always paid. The man was more contented, and became then an advertising agent both for the firm using the vehicle and the maker thereof.

He was sorry he had not with him any figures with regard to the cost of alcohol; so he could not reply to Mr. Walker fully, but the use of alcohol was certainly a thing which ought to be gone into very carefully because it could very easily be produced in large quantities, and there was no doubt that by specially arranging

the engine it could be used most efficiently. Mr. Walker had touched on the question of the most economical speeds, and he might mention that in America some years ago they went very fully into the whole question of motor transport and took careful statistics over a number of years, when it was proved quite conclusively that the most economical speed for a motor-vehicle was roughly twice the speed of a horse. Taking very heavy traffic, the horse no doubt averaged about $2\frac{1}{2}$ miles per hour, so that 5 or 6 miles would then be the economical average speed for the motor-vehicle for a similar class of work. The average speeds in this country were higher than in America, and he understood that a bonus system based on the same principle, but in which the average speed of the vehicle was taken at 6 to $7\frac{1}{2}$ miles per hour, varying with the town in which one was working, was in successful operation. He had given some figures in the Paper with regard to the speeds of working which he had not read that evening but which the members could see for themselves.

On page 688 he stated, "The *Central Station of America* published some time ago the following results of a series of tests between a petrol and an electric lorry geared respectively for a maximum speed of 12 and 18 miles per hour." The results showed that the average speed of the electric vehicle was approximately 10 per cent higher, although geared and powered for a 30 per cent lower speed. It was necessary that these particular classes of vehicles should be kept to their own districts. He instanced a case where a petrol and an electric vehicle had been working between points on opposite sides of London, the route passing necessarily through the City. The electric vehicle was geared for about 14 miles per hour and the petrol for about 18 to 20 miles per hour, but the petrol vehicle could not beat the electric by many minutes. In that case they were working through a congested area in the centre of London with no very long run on which the petrol could use its speed.

Mr. Stone referred to "caterpillar" traction (page 726) and the obtaining of low specific pressure. The tractor illustrated in the Paper gave a pressure of about 3 lb. per square inch which was a

(Mr. C. G. Conradi.)
long way below even the pressure between a man's foot and the ground. He thought that was really the lowest pressure which had been got from a "caterpillar" machine. Of course these were quite special vehicles and not for ordinary use. Mr. Stone had referred to the "Electric" competing with the "Petrol," and the Author was of opinion that there should be little competition between the two, each having quite a well defined field of activity. He could not follow Mr. Stone with regard to the efficiency of the battery which he put at 10 per cent. The ampere-hour efficiency, for instance, was 85–90 per cent, and if Mr. Stone took the watt-hour efficiency taking voltage into account it was about 70.

Mr. F. Stone explained that he was regarding the efficiency as about 90. It was the initial efficiency that he was referring to. The thermal efficiency of most power stations very rarely exceeded 10 per cent. It used to be about 7 per cent a few years ago, but since they had had turbo-generators and other things it had gone up to about 15 now. So in a battery, even if they assumed 100 per cent efficiency they would only get 10 per cent of the energy of the coal. He did not refer to the efficiency of the battery.

Mr. Conradi agreed that was so. Of course, taking the value of the efficiency, it was certainly low, but the electric vehicle obtained its power in a very cheap and convenient form, therefore the cost of running it was exceedingly low.

In replying to Mr. Paxton (page 728) he pointed out that what he meant was that vehicles working with trailers should not be allowed to pass through congested areas. That was the point he had in view, and not the actual use of trailers at the docks. But if they came down to the docks question, he thought the fact that they were using trailers and fixed bodies very largely accounted for the congestion there. First of all, they were using a two-unit combination which was very difficult to manœuvre with any degree of accuracy, and in most cases they were hand-loading both the vehicle and the trailer. What ought to be done away with was the hand-loading. If they had standardized removable bodies in

some form which could be loaded up ready for the vehicles on arrival they would have quite a different result. Instead of the chassis being at the docks for say five hours, as Mr. Fine had mentioned, it might be there only five minutes. One installation which was using removable bodies wholly had reduced the loading time—that is to say, the total terminal delay in the yard—to twenty minutes, and there was no doubt that further organization could bring that down still further, but even twenty minutes was a very big difference from five hours.

With regard to Mr. Allen's remarks (page 729), the tractor was a most useful machine and he thought it would pay in the case which Mr. Allen mentioned. One instance occurred to him where a tractor was doing 36 tons per day over a longer run than Mr. Allen had to deal with—a case of a steam-tractor and trailers supplying a paper-mill—and the trailers could be dealt with quite easily by a small electric tractor; in fact, he had experimented with a small electric platform truck and found that even that could be made quite suitable for the movement of trailers, and no doubt a machine specially designed for the job would do better still.

With regard to Mr. Fine's remarks as to time lost at the docks (page 730), he certainly thought that a trailer got in its own way—if he might put it so, and his reply to Mr. Paxton's criticisms expressed his views on this point. The electric vehicle was certainly not in the field for long-distance work, but if a petrol-motor were added it was quite a useful unit, and before very long he hoped to see the law altered so that they might be able to use road trains, in which case one tractor could deal with five or six trailers. Several systems were already in existence, ready to do this work, and all they wanted was an opportunity of using them.

A vote of thanks to Mr. Conradi concluded the Meeting.

Discussion in Sheffield on Friday, 28th November 1919.

The CHAIRMAN (Dr. William Ripper, C.H., *Member*), in opening the proceedings, thought that all present would desire to express to the Council of The Institution of Mechanical Engineers their great appreciation of the enterprise of the Institution in allowing those Papers which were read in London to be read in certain centres of industry where the subjects dealt with were of great local interest. The Papers were usually of a very good type, and their continued discussion by persons of competence and ability, and with the knowledge that came from experience, contributed much valuable information, and enriched the literature of The Institution.

The subject of mechanical road traction was obviously one of the greatest interest and importance to Sheffield. They learned during the War the great possibilities of road transport, and the country also realized as a result of the dislocation and congestion of traffic how inadequate the railways were to meet the needs of great centres such as Sheffield. The necessity of improved organization and arrangement and direction of this powerful means of helping in the distribution of material was obvious. There was a world of problems connected with this industry—motive power, accessories of the power, loading, unloading, collecting and distributing the goods carried. All these were questions for the engineer, and suggested tremendous possibilities for the application of practical knowledge in their solution.

If it were ever supposed that the young engineer was not going to have plenty to do in the future, the coming of this great movement of motor transport was sufficient to dispose of that idea. In this question of the growth and development of road transport they must have the advantage of men of experience, and that was why they welcomed Mr. Conradi warmly, who would, he was sure, throw light upon the subject.

Mr. C. G. CONRADI then gave a summary of his Paper.

The Chairman, before inviting discussion on the Paper, read letters from Mr. W. J. Hadfield and Mr. Harry E. Yerbury, as follows :—

Mr. W. J. Hadfield (City Surveyor of the Corporation of Sheffield) wrote that he was in entire agreement with the Author in thinking that one of the vital necessities in developing heavy motor traffic was to improve the means of loading and unloading which at present caused such a serious waste of time. His Department was running thirty-five to forty heavy motors each day. They were used not only for the conveyance of goods, but also for street sweeping, street watering, haulage of snow ploughs and numerous other purposes. They were using motors to-day for work which five years ago would have been thought generally to be quite outside their scope, and he had no doubt that within the next few years this form of traction would displace other forms to an even greater extent.

Mr. Harry E. Yerbury (Deputy General Manager of the City of Sheffield Electric Supply Department) wrote that the Author's remarks on road engineering would be endorsed by all users. The subject of road construction and maintenance was of vital interest to the general community. Perhaps the time was not far distant when it would be recognized by the Treasury that roads were a national concern, and as such should be maintained out of National Funds from revenue derived from the present tax on petrol. The economic features of any particular system of road traction could only be studied in conjunction with the conditions prevailing in the particular district. He agreed with the Author that up-to-date loading and unloading methods must be adopted, so that each vehicle was actually working the maximum number of hours per day, and the demountable body with legs would assist in that direction.

The Author brought out the prominent features of the electric vehicle which was already largely used in Sheffield for refuse disposal. An electric vehicle had its limitations, and for work on bad roads and stiff gradients could not be recommended. This fact

(Mr. Harry E. Yerbury.)

was demonstrated in Sheffield to the makers of both lead and Edison batteries, and petrol and steam lorries only were now doing the work. The use of rubber tyres was advisable on every type of road vehicle, as it brought down the total cost of maintenance.

The vehicle with a self-contained crane, as built by the Yorkshire Motor Co., was an admirable arrangement for heavy goods, and two of these were now on order for the Sheffield Corporation. The adaptation of the roller-blind shutter for truck discharging purposes was useful for certain classes of goods, but owing to its light construction it was apt to become distorted and useless.

Regarding the comparison of working costs of the three systems, he would be glad to know how the respective costs in pence per mile run were made up (as shown in Fig. 45, page 685). In other words, what was the figure taken for electrical energy, petrol, coal, or coke, and wages for the three vehicles. It had, he thought, been proved that a cheaper class of man might be employed in handling an electric lorry compared with a petrol or steam vehicle, and the total maintenance costs were the lowest.

Regarding the Author's remarks on passenger transportation, he thought the three principal factors governing this service were capacity, capital expenditure, and working expenses. There were many divergent views expressed which, however, generally settled themselves on an economic basis. He could not endorse the Author's opinion that "the tramcar appears to have had its day of usefulness." He would advise him to read a Paper by the General Manager of the Sheffield Tramways, which was given before the Municipal Tramways Association at Dundee this year. Actual costs of petrol vehicles compared with tramway costs were given, and on the basis of these costs it was clearly proved that the petrol motor was not going to supersede the electric tramcar. Presumably, the London County Council had arrived at the same conclusion recently. Rail-less cars and motor-omnibuses acted as excellent feeders to the tramways, and he thought their field of usefulness lay in that direction. The latter class would always be keen competitors on account of their greater flexibility to take up service on any route where traffic was demanded. Their

comparatively short life and high maintenance costs were dead against them. Evidently their useful life was deemed to be shorter than trolley-omnibuses, for only five years' borrowing power could be obtained as compared with ten years for other vehicles. There was a useful field for all classes of vehicles, and the Paper would doubtless prove very useful as a guide in such matters.

Mr. C. K. Everitt said that at his works there were about half-a-dozen small electric trollies for running about the works, and they had been found very reliable and extremely simple in use. During the War, girls ran these vehicles about very successfully after only a little tuition. The trollies could always be depended upon, and he was sure they were a type of vehicle the use of which might with advantage be considerably extended.

With regard to road transport, he thought mechanical traction suffered a very considerable handicap on account of the condition of the roads, which had had little or no attention for the past five years, and were now in a deplorable state. The roads were certainly responsible for very heavy repair bills for those vehicles which attempted to run at anything like their maximum speed. He had a shock when he heard that tramways had had their day, but he remembered that he had had a similar shock many years ago when their doom was prophesied, and he then wondered whether his firm (Messrs. Edgar Allen and Co.) would have to go out of business as manufacturers of tramway track work; that did not happen, and he did not think it would happen to-day. Mr. Yerbury had put the case for the tramways very clearly in his letter, and the Paper that was read at Dundee and the statement made by Mr. Fell of London would, he imagined, give the tramways a new lease of life. He thought, in connexion with mechanical traction, the point to which the Author devoted considerable attention was a most important one, namely, that of loading and unloading. He was sure that, altogether apart from the vehicles themselves, a method of loading and unloading by some suitable arrangement would more than double the value of the vehicles.

Mr. T. W. Willis (President of the Sheffield Society of Engineers and Metallurgists) said he had been running two 3-ton steam-wagons, and his experience agreed with the Author that the great loss was in the time occupied in loading and unloading. He had two wagons exactly the same size and almost the same age and condition, but the running costs did not work out the same, and with different classes of work the cost per ton varied very much. He had also had a petrol-wagon, but had found that with the heavy work demanded of it—loading with heavy steel and getting knocked about very badly—this type of vehicle soon went to the scrap-heap. He desired to thank the Institution of Mechanical Engineers on behalf of the Sheffield Society of Engineers and Metallurgists for the opportunity of its Members being present that evening, and he regretted there was not a larger attendance.

Mr. R. J. Armstrong said there was no doubt that a container was an ideal arrangement for reducing working expenses on any type of mechanically propelled vehicle. His firm (Messrs. John Walsh, Ltd.) introduced the steam-wagon into the removal trade in Sheffield about ten years ago. At their premises there were cranes for slinging the vans on and off. It was very seldom that their steam- or petrol-wagons would be seen in the city loading or unloading. It was his practice to do the collecting mostly with horsed vehicles, and then pick up the loaded vans with the travelling crane at their depositories and put them on motor-wagons for dispatch to the stations or to all parts of the country. Of course that secured one very important consideration—that the motors ran full. On 70 per cent of their journeys their motors were run with a full load, so that they were able to give the public the benefit of the reduced running costs as well as to earn more profit for themselves; and in every way a better average percentage was shown for the vehicles. In his opinion, the great drawback to mechanically propelled vehicles to-day was that road surveyors were not keeping pace with anything like the speed that the makers were with the machines. Of course, it must be remembered that the War had had much to do with the present

state of the roads, but if mechanical transport was to succeed, municipalities must remove many of the restrictions with regard to mechanically propelled vehicles. The Police must also remove some of the restrictions with regard to speed, because, as the Author agreed, a steam-wagon drawing a trailer at five miles an hour was not like anything as good a proposition as a steam-wagon drawing a trailer at say twelve miles an hour, especially if the trailer was on rubber tyres. Until he could run at twelve miles an hour or better roads were provided, he would decline to put a trailer on rubber tyres.

Mr. HUGH LEADER said that, with regard to the question of the trams, he could understand that those who sold tram-rails felt disturbed when it was suggested that the rails should be done away with. He did not think that the comparison which Mr. Yerbury made—as he understood it—between trams and petrol-vehicles was a fair one. What he would like to know was how tramcars, propelled by the overhead trolly, compared with trackless vehicles propelled in the same way, such as were running in the Rotherham district and in other places in the country. Mr. Yerbury had asked for information as to the chart on page 685. It seemed to him (the speaker) that what they particularly wanted to know as regarded that chart was on what mileage per day the figures were calculated. This point made not only a great deal of difference, but all the difference, in considering the merits of the three different types of vehicles. Actual figures of cost were likely to be interesting to those present. He had worked out the cost of a trip of a 5-ton "Sentinel" wagon, which he believed was fully loaded both ways—a trip of 44 miles from Sheffield out, and back. The wagon carried a rather heavy on-cost for charges, because it was connected with a big firm in which everything had to pay its share of the total standing charges, so that it could hardly be compared with a single lorry, owned by a small firm, on which the standing charges were practically negligible. The actual running time on the 88 miles was about thirteen hours, and unloading and loading time at the other end was two hours,

(Mr. Hugh Leader.)

making a total of fifteen hours between the time when it started out, at 6 a.m., and the time it got back. He estimated that very likely an hour should be added to this time for the time spent in getting up steam and loading in the morning, and the time taken up in going to the garage and getting things straight before the men went home, making a total of sixteen hours. That worked out at an average speed of $5\frac{1}{2}$ miles per hour, and, taking the hourly cost of the vehicle and reckoning that it was fully loaded both ways, it gave a cost per ton-mile of $1 \cdot 66d.$, or $3 \cdot 22d.$, if they reckoned that it was loaded only one way.

He had had a good deal of experience of small electric trucks made in America, and one or two English makers had now begun to manufacture them. During the War he had tried to get them from English makers, but everyone seemed to be too busy with other work. The great defect which he found in one type was that the wheels were too small for convenient use on ordinary roads, being only 15 inches in diameter. Finally he came across a type which had wheels of 20 inches diameter, and stronger chassis, and they were very much more satisfactory.

With regard to the motors on the small 2-ton trucks, and on the ordinary electric trucks, he thought one of the reasons why electric vehicles in Sheffield were found to be not so successful as they might have been under more favourable circumstances, was that most of them were fitted with Edison batteries. Now they could not, on an Edison battery, boost the output as they could with a chloride cell. The latter was capable of a sudden spurt which the Edison battery would not give them. If the vehicle got into soft ground, or on to a specially steep short bit of hill, they might be able to get out with a chloride battery, whereas an Edison battery would keep jogging along at one power output all the time, and they could not boost it up a bit. That might be one reason why some of those that were tried in Sheffield were deemed a failure.

Mr. A. Bayliss thought they would have better locomotion on the roads when they had arrived at a standard vehicle. His great

trouble in transport had always been the difficulty of getting spare parts to replace those broken in connexion with the engines or parts of the vehicle. It might be that he had chosen some outstanding car. But he believed that the Ford and one or two other firms were trying at the moment to manufacture something which was a standard fitting, whereby anything that was broken could be readily replaced. There was one method of loading not mentioned in the Paper, which he adopted some years ago in the Midlands, and found very successful. He backed the lorry up to a raised deck, which had rails in certain parts and a capstan at one end, and by means of casting a rope on to the capstan the goods were pulled on to the lorry. This was found to be a very efficient way of loading up a lorry. One other method—which, however, could only be adopted where iron and steel in large quantities were concerned—was the use of the electro-magnet. This was dropped on the work, the current was switched on, and the plate was taken up and put on to the lorry or anywhere they desired.

With regard to tramcars, he was never more disappointed with them than he was when he came to Sheffield. The cars ran much too close to one another. Only the other day he witnessed an accident, one tram crashing into another one. He believed the Board of Trade regulations provided that tramcars should be three poles apart. Sheffield had still to learn those regulations. As to tramcars having served their purpose, there was one very useful arrangement which should be adopted in Sheffield that was in force in Birmingham, namely, the express tram service for goods. At nearly every terminus in Birmingham there was a luggage office, where goods could be left, which were collected by the tramways parcels post, and taken in all directions, even as far as 20 miles from one place to another. Presumably this system did not exist in Sheffield, and he suggested that it was worth looking into.

Another matter to which he thought they must look forward before they got a good, systematic, mechanical road traction working, was a cheaper fuel. It was costly to transport material

(Mr. A. Bayliss.)
with the fuel they had at present. Mention had been made of the employment of cheap labour in connexion with these vehicles. His experience, not only as an employer of labour but also as an employer of men on those vehicles, had been that cheap labour was dear labour. It was like the cheap machine—one must not expect good things from it. The man who learnt his job in a few minutes or a few hours, and got out on the road with a mishap, usually caused more trouble than a man to whom they had to pay twice the same wages, but who could bring the car back again into the garage, all in order. The sooner they turned their attention to these matters, the better it would be for them from a commercial standpoint, whereby their goods might be taken from place to place with ease, with comfort, and, still more important, with rapidity.

Mr. P. Hewitt asked whether the Author thought it possible, at the present time, to compromise on the question of tyres, so that the roads could be left usable for both horse-haulage and mechanical traction. There was no doubt that at present roads were being made for mechanical traction, and horse-haulage appeared to be considerably jeopardized. He would like the Author's opinion as to whether, for some years to come, a class of tyre could not be brought out which would suit the present horse-haulage and also be onsistent with mechanical traction.

With regard to cells in electric conveyances of all kinds, he said that after a time all electric cells tended to give out. They might be charged to their full capacity, but, when their efficiency was going, naturally one did not get out of them what one expected. Although one might set out with his cells fully charged, the time would come possibly when the discharge would take place much quicker than in the early days of the cell. He would like to know if the Author had come across any means of testing the efficiency of those cells, and if he recommended the cells after so many years' usage. He did not quite agree with one of the previous speakers with regard to the Edison and chloride cells. In his opinion, the Edison cells were very good, and he had used them a great deal. They would stand a heavier discharge, and would give that spurt

which the lead plates would not. Further, the lead plates would not stand the vibration of the heavy shocks to which all vehicles were subjected while travelling.

Mr. C. G. Conradi, in reply, thanked those present for the kind way in which they had received the Paper. He had not with him all the figures which went to make up the curve on page 685, but with regard to fuel he might say that coke was taken at 30*s.* per ton, current at $1\frac{1}{2}d.$ per unit, and petrol at 2*s.* 6*d.* per gallon. Labour was assumed to be practically equal in the case of petrol and steam, but a few shillings less in the case of the electric vehicle, which he thought was quite justified; in fact it was taken from actual experience.

Mr. Bayliss had taken exception to the employment of cheap labour in the case of drivers (page 744), but, so far as electric vehicles were concerned (and it was to these he understood that the previous speaker's suggestion referred), he (Mr. Conradi) believed it to be quite sound. The electric vehicle was a much simpler tool to handle in every way than either of the others, and it was absolutely unnecessary to have a skilled man to run it. In all the cases with which he had had to deal—involving probably 200 drivers—every man had previously been a horse-driver. These men were chosen first of all because they knew the route and the business that was being done, and from that point of view required no teaching. It was quite easy to teach an intelligent horse-driver to take over an electric vehicle in, at the very most, three days; in fact he knew of cases where men had taken vehicles out without any tuition at all, and with no bad results. In the City of Sheffield the Midland Railway Co had six electric vehicles running, and three of them, he believed, in 1918, lost not one day in the whole year. It would, in fact, have been quite possible, if specially arranged, to run the bulk of the vehicles for 365 days in the year. But he did not recommend that course, because it paid to stop a vehicle at stated intervals. In the large fleet with which he was recently connected they made it a rule to stop every vehicle for two days per quarter for examination.

(Mr. C. G. Conradi.)

He was referring now to electric vehicles. Petrol or steam vehicles required much more attention than that. In the case of the electric vehicles, it had been proved that, where systematic attention was given, the vehicles as a whole lost less time than in other towns where the rule was not so strictly enforced and where the vehicles ran until they were forced to stop, probably because of the breakdown of some small detail part whose defective condition would have been revealed by the periodical examination.

Mr. Yerbury rather took him to task on the question of the trams (page 738), but he was afraid that gentleman was looking at the matter from a one-sided point of view. The trams, or rather the track, did a very great amount of damage to the vehicles of the other users of the road, and they caused in many cases great obstruction, for instance, only on Wednesday morning last a line of L.C.C. tramcars a mile long was held up by a breakdown at Vauxhall. Taking these points into consideration, he certainly thought that the extension of tramways would be very limited. The London County Council had been instanced, and they all knew the very extensive programme which that body had put forward. But would it be carried out? He ventured to think that only a small portion of it would ultimately go through. One had only to walk down the Sheffield streets to see what damage the rails were liable to cause. He had seen rails in Sheffield standing at least three inches above the surrounding paving, and if any vehicle which was not rail-bound tried to traverse that road at an angle one could easily imagine that some damage at least would be caused to it. In fact Sheffield was known by tyre-makers to be an exceedingly bad spot as regards tyres, and makers were very chary of taking contracts for them in that city.

He was very much interested to hear Mr. Armstrong's experience (page 740). Certainly that gentleman was doing well to get an average of 70 per cent full loads. He had been speaking that morning to Mr. Fine, who was now running the Manchester Transport Exchange, and was very much interested in what he saw there with regard to the amount of time being saved by quite a small organization. He said a "small organization," although

as a matter of fact, Mr. Fine was working as an exchange for nearly a thousand vehicles—he formed the link between the user and the owner, but he got through a lot of work with a small staff and simple yet effective methods. Mr. Fine gave him many instances of the delays at, for instance, Liverpool Docks. It was quite common—in fact it was almost the average—to find that five hours were lost by vehicles going there for loads. They lined up in queues, and had to wait their turn. That appeared an absolutely ridiculous state of affairs in these days, and there was no reason, to his (the speaker's) mind, why it should not be very quickly altered. He thought it was really only a question of organization, and the use of some simple demountable body arrangement.

Mr. Leader had referred to the comparison of trolly-omnibuses and tramcars (page 741). Again, he was sorry that he had no actual figures with him, but if Mr. Leader had the tramcar figures he (Mr. Conradi) could give him the trolly-omnibus figures. In any case, he would be glad to put them into the records of the Institution. With reference to the question of "Ironclad" versus Edison batteries, it was one which he purposely left out of the Paper, and one on which there might be much controversy. Personally, he thought that there was quite a good field for both, but they must be kept to their particular work. The "Ironclad" had probably an average life of three years, and there was no doubt that for heavy work it would give a better performance than the Edison. The Edison would certainly give a heavy discharge—it would give them anything they wanted in that way—but it would not give it at any reasonable voltage, so that from a hill-climbing point of view the Edison battery was defective. The reason for this was that the internal resistance of the Edison battery was high compared with that of the lead battery. The "Ironclad," on the other hand, would give its discharge, with a smaller percentage drop in voltage, and a better performance be obtained on hills. In a town such as Sheffield he would always prefer the lead battery. If they went further into the battery question, and looked at it from the commercial point of view, he did not think there was really much to choose between the two. The lead battery required

(Mr. C. G. Conradi.)

more attention, and against that the Edison took more current and therefore they had to choose their ground to some extent. If current was dear, or the town was hilly, use the lead, but if current was cheap or skilled labour scarce and they were operating in flat country, then use the Edison.

Mr. Hugh Leader asked what the Author estimated the life of the Edison battery to be.

Mr. Conradi replied that this had not been definitely found out yet, but he thought it was fairly safe to put it at eight years. He agreed with Mr. Hewitt that there was a great deal of trouble at the present time with horse-traffic on the smooth roads which were certainly being prepared, mostly from the motor point of view; and unfortunately he did not see any way of helping the horse out of his trouble. With regard to cells running out, every vehicle was, or should be, provided with a meter with a special dial. One such was the Sangamo, where there was a large dial, and a good practice was to put a red mark on that dial at the point where the battery was very nearly run out, so that the driver could always see when he was coming to a point at which he ought to be near home as regarded battery capacity. Once a driver's attention had been called to this, there was really very little trouble from this cause, and cases of vehicles being towed home were very few. To prove the state of a battery it was an easy matter to make a capacity test, which could be done by running the battery down through a resistance of some kind, with an ammeter in circuit, and then comparing the result with the original capacity.

Communications.

Mr. A. L. Haas wrote that transport was as vital to manufacture as production, and it was difficult to say which was the more important from an economic point of view; the two things were complementary, for it was little use making things if they could not reach the consumer with speed at a cheap rate. Inefficient transport imposed a tax upon the community at large, and while production had received systematic attention—for this was the outstanding feature of modern management—transport remained chaotic, to the loss of all. The Author had done well to call attention to a matter which had received more attention abroad namely, the betterment of terminal facilities for loading and unloading, by the improvement of the vehicle itself to this end. The larger question of systematizing transport had been wisely left untouched, also that of road work itself, for both were more or less political questions although insoluble without the mechanica engineer.

A familiar feature in the streets of Ipswich for many years had been the system of detachable bodies on four legs with castors used for works transport by Messrs. Ransomes, Sims and Jefferies. The foundry of this firm was at a short distance from their other shops, and a system of removable containers on the same principle as that shown in Fig. 8, Plate 19, was used. The writer was uncertain how long the system had been in operation, but from personal observation he thought it was for many years; it would seem, therefore, that it was unnecessary to go to the United States for an example of this means of keeping idle time at a minimum for the power unit.

The other solution of keeping the idle time of the power unit at a minimum was by having the power member separable; this was noticed in Fig. 17, Plate 21. A much more ingenious solution was an American production termed the "Auto-Horse." In this, a petrol motor and driver's cab were mounted on a single wheel having three solid rubber tyres abreast; steering and driving were effected through the single wheel, and the whole cab was revolvable

(Mr. A. L. Haas.)

upon a spur-gear ring, the steering wheel being pinion-geared into this base ring. Two steady wheels were fitted on rear arms for the purpose of running alone, and any ordinary trailer of railway or other type could be used when specially fitted. The construction allowed propulsion (driving backwards facing the load) as well as traction, and turning could be effected in a very small radius. The device was thoroughly tested under all conditions by the Munitions Inventions Department, and this type of design under conditions of short haul with delayed loading or unloading gave considerable promise. The transmission had unusual interest since it was carried by two shafts at right angles, the actual chain-drive being parallel to, and at the opposite side from, the axial line of the engine.

A comparison of the normal fire-engine boiler with the "Sentinel" boiler shown in Fig. 46, Plate 26, was of considerable interest; the possibilities of the vertical-type boiler when specially designed for light weight and quick steaming were considerable. This was a side issue raised by the illustration given, but worth attention.

Mr. Edmund White wrote that when he was a Government Inspector during the War he found the use of the Jacktruck a great labour-saver in the Shell Factories in the various stages of operations, and most useful when women labour was employed, as it was readily and easily handled.

Mr. Conradi wrote with regard to Mr. Haas' communication that he would like to correct the impression that the demountable body shown in Fig. 8, Plate 19, had been imported from America. It had been designed by the Author some years ago and differed from that described by Mr. Haas in that the castor-feet were made to turn up out of the way, so as to allow of the body being lowered on to the chassis, the height of the platform being of considerable importance in general delivery work.

Another feature of the design was that the front legs could be opened out to allow of easy entrance of the chassis to pick up the

load and subsequently be closed in again so that they did not project beyond the body and give trouble in traffic.

No attempt had been made in the Paper to catalogue all the designs of motor-vehicles in existence, but the "Auto-Horse" mentioned by Mr. Haas was certainly an ingenious form of tractor. It appeared to him, however, that it would take longer to connect up than some of the other types, although it had the advantage of the large lock which was obtainable.

Further to his remarks in reply to Mr. Stone on the question of thermal efficiency (page 734), he thought the following comparison might be useful. It was based on vehicles of 40-cwt. capacity which was hardly fair to the steam-vehicle, but it could not be avoided unfortunately.

Type.	Thermal Efficiency.	Fuel cost per mile.
	Per cent.	Pence.
Horse . . .	1·27	4
Petrol . . .	8·15	4
Steam . . .	1·14	1½
Electric . . .	5·38	1¼

The comparatively low efficiency of the "Steamer" was due to the high stand-by losses.

The Institution of Mechanical Engineers.

PROCEEDINGS.

December 1919.

An Ordinary General Meeting was held at The Institution, London, on Friday, 19th December 1919, at Six o'clock p.m.; Captain H. Riall Sankey, C.B., R.E. (ret.), *Vice-President*, in the Chair.

The Chairman, having requested the members to stand, said it was with great regret that he had to announce the death of Mr. J. Hartley Wicksteed, a Past-President of the Institution. Many of the members would remember how well Mr. Wicksteed conducted the Meetings when he was in the Chair. He became a Graduate of the Institution in 1868, a Member in 1882, he was on the Council from 1885, and was President during 1903 and 1904. At its Meeting that afternoon the Council had approved a letter to be sent to Mrs. Wicksteed, which it was perhaps unnecessary to read here; it expressed the high appreciation in which Mr. Wicksteed was held, and he was sure the members would approve of such a letter being sent.

The Minutes of the previous Meeting, held on 21st November, were confirmed and signed.

The Chairman announced that the following four Transferences had been made by the Council:—

Associate Members to Members.

Bruce, Archibald Kay, ...	London.
Dickinson, Henry Winram, . . .	London.
Duckett, Walter, ...	Birmingham.
Wilkinson, Lionel St. George, M.C., . .	Crewe.

The Chairman announced that the Council had made a grant of £2,000 towards the James Watt Memorial, and the instructions of the Council were that the money was to be spent on the building

to be erected in Birmingham. The following letter addressed to Mr. Askquith Ellis, Honorary Secretary of the James Watt Centenary, would explain the matter to the members:

DEAR SIR,

The Centenary of the death of James Watt is an event of universal interest to Engineers, but to none more so than to the members of The Institution of Mechanical Engineers. Many of the members were privileged to join in their individual capacity in the recent celebrations at Birmingham, at which The Institution was also officially represented. The proposals of the Birmingham Commemoration Committee to found a Watt International Permanent Memorial have been reported to the Council of The Institution, and have had their careful consideration.

The Council hope that the Memorial Hall, which it is proposed to erect, will be a worthy Memorial to the genius of James Watt, and I have pleasure in informing you that they resolved unanimously to offer a sum of £2,000 towards the cost of the Building,

I am, Dear Sir,
Yours very truly,
EDGAR WORTHINGTON,
Secretary.

R. B. Askquith Ellis, Esq., Hon. Secretary,
James Watt Centenary,
Chamber of Commerce Building,
New Street, Birmingham.

The following Paper was read and discussed:—

"Cutting Power of Lathe Turning Tools: Part II"; by GEORGE W. BURLEY, Wh. Ex., of the University of Sheffield, *Associate Member.*

The Meeting terminated at a Quarter to Eight o'clock. The attendance was 93 Members and 43 Visitors.

The Paper by Mr. Burley was also discussed at:—

MANCHESTER, in the Engineers' Club, on Tuesday, 23rd December; Professor G. GERALD STONEY, F.R.S., *Member*, in the Chair.

BIRMINGHAM, in the Medical Lecture Theatre of the University, on Thursday, 1st January 1920; Sir GERARD A. MUNTZ, Bart., *Member of Council*, in the Chair.

SHEFFIELD, in the Mappin Hall of the University, on Monday, 5th January 1920; Mr. HARRY E. YERBURY, *Member*, in the Chair.

CUTTING POWER OF LATHE TURNING TOOLS: (PART II).*

(BEING AN ACCOUNT OF FURTHER EXPERIMENTS MADE IN THE MACHINE-TOOL LABORATORY OF THE UNIVERSITY OF SHEFFIELD.)

BY GEORGE W. BURLEY, WH. EX., OF THE UNIVERSITY OF SHEFFIELD, *Associate Member.*

INTRODUCTION.

The present Paper, the presentation of which has been delayed on account of the War, constitutes the second part of the Paper * on "Cutting Power of Lathe Turning Tools," which was read before the Institution in November, 1913, by Professor W. Ripper, D.Eng., D.Sc., and the present Author. It deals with a continuation of the series of experiments made with lathe turning tools, working on steel, described in the original Paper, and in it, amongst the matters dealt with, are a number of points which were raised during the discussion on that Paper.

* Part I, Proceedings, I.Mech.E., 1913, Part 4, page 1067, with Figs. 1–67, and Appendixes I–VI.

The following points relating to the question of the cutting qualities and efficiency of lathe turning tools when working on steel are considered in the sequence given :—

1. The relation between the cutting speed and the degree of finish obtained by the use of ordinary lathe finishing and light-cutting tools.

2. The relation between the cutting speed and the durability of ordinary lathe finishing and light-cutting tools.

3. The influence of different rake angles upon the cutting power of high-speed lathe roughing tools.

4. The relation between the rake angles of high-speed lathe roughing tools and the power consumed in cutting.

5. The influence of the nose-radius and that of the cross-sectional area of the tool steel upon the cutting qualities of lathe roughing tools.

6. The influence of the height of the cutting edge upon the cutting efficiency of high-speed roughing tools.

7. The influence of the forging operation on the nose of a lathe turning tool upon the cutting power of the tool.

8. The influence of the direction and active length of the cutting edge of a high-speed lathe roughing tool upon the net amount of power consumed in cutting.

9. The relation between the cutting speed and the net amount of energy required to remove a cubic inch of steel by means of a high-speed turning tool.

10. The relation between the use of cooling agents in turning operations and the cutting power of high-speed turning tools.

11. The influence of cooling agents upon the net power consumption when high-speed turning tools are employed.

12. The condition of the cutting edge of a lathe turning tool with respect to the cutting efficiency of the tool.

Each one of the tests herein described was made on one or other of the two lathes already described in the original Paper ; the tests which involved roughing cuts, tools of large sections, and power measurements being made on the large electrically-driven experimental lathe ; whilst those involving finishing cuts were made

on the small lathe fitted with a variable-speed mechanism. Further, the materials on which these experiments were made were identical with those used in the original sets of experiments.

1.—Relation between Cutting Speed and Character of Surface formed by Finishing Tool.

One of the principal objects of the experimental work outlined in the first Paper was to determine whether the remarkable results * in connexion with the durability of cutting tools which are obtained on the "Herbert" tool-testing machine are comparable with the results of tests on tools in the lathe under conditions conforming to those which operate in ordinary lathe practice. It was shown that, with both plain-carbon and high-speed steel tools working under ordinary cutting-tool conditions with cuts which, for the sections of the tools experimented with, could be classed as roughing cuts, no results similar to those of the "Herbert" test were obtainable.

To cover a still wider field in connexion with this matter, a continuation of the research has been made with tools working under very light finishing-cut conditions in contrast with the conditions of the original research.

Tool Steels.—The tools employed in these tests were made variously of three varieties of tool-steel, as under :—

(*a*) Plain carbon tool-steel, containing about 1·3 per cent. of carbon ;

(*b*) Ordinary high-speed tool-steel, containing about 14 per cent of tungsten ;

(*c*) Superior high-speed tool-steel, containing about 18 per cent. of tungsten and about 0·75 per cent. of vanadium.

Test-Bars.—The tools were tested on steel bars of two qualities, namely, mild steel and very hard steel, the chemical compositions and

* Proceedings, I.Mech.E., 1913, Part 4, page 1068.

physical properties of these steels being given in Appendix VII and VIII (pages 821–2) respectively under the letters W and Z. These bars were initially about 2 feet 6 inches in length and 6 inches in diameter.

Fig. 68.—*Finishing Tool for Mild Steel.*

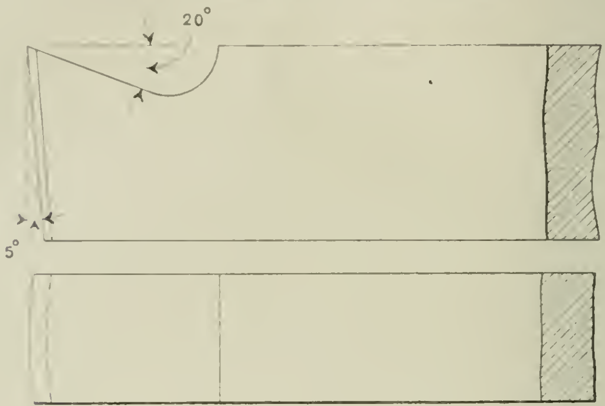
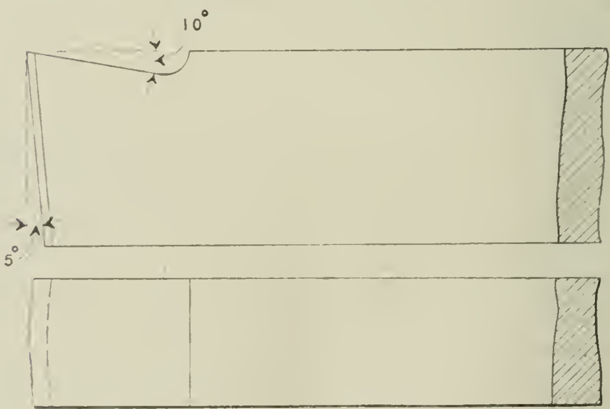


Fig. 69.—*Finishing Tool for Hard Steel.*

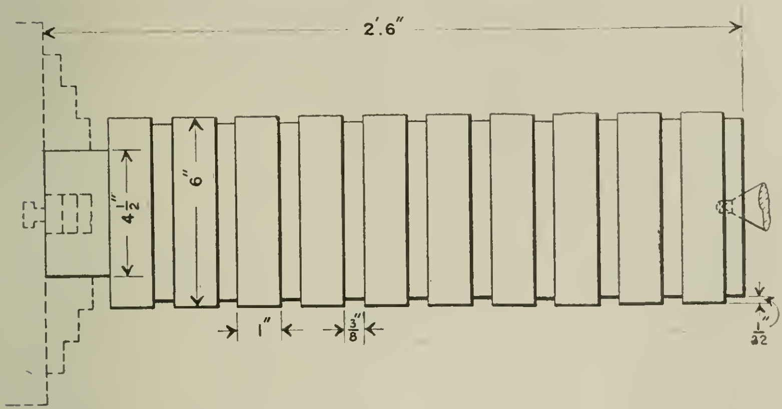


Tools.—The tools used in the tests were made from bars $\frac{3}{4}$ inch by $\frac{1}{2}$ inch in section, and were about 12 inches long. The shapes of tool nose and the angles adopted are represented in Figs. 68 and 69,

the former indicating the shape and angles of the tools tested on the mild-steel, and the latter those of the tools tested on the hard-steel bar. The cutting edge of each tool was ground to a very large radius, with a front rake angle of 20° and 10° for the soft and hard bars respectively, and a uniform front clearance angle of 5°, there being no side rake or side clearance ground on the tools.

Standard of Test.—The degree of smoothness or finish of the surface of the test-bar formed by each tool was taken as the

Fig. 70.—*Test-Bar for Finishing-tool Tests.*



measure or modulus of the efficiency of that tool, it being assumed that a lathe finishing tool is useless as such at any cutting speed at which it does not produce a smooth surface. To determine the degree of finish in each case, several methods were experimented with, but since in every case the standard or critical degree of finish had to be based on human judgment, it was finally decided to depend, in the first instance, solely upon the combination of the independent judgments of a number of experienced observers based upon ordinary visual examination of the surface of the bar.

Method of Testing.—For this set of tests, each test-bar was divided into a number of one-inch lengths, separated by shallow

grooves $\frac{3}{8}$ inch wide, as indicated in Fig. 70. The *modus operandi* was to take each tool, hardened, ground, and oil-stoned ready for use, and to run it on the first inch-length of the test-bar at a definite low cutting speed, with a depth of cut of 0·004 inch and a feed of $\frac{1}{24}$ inch per revolution. It was allowed to traverse the whole inch-length, and was then removed and resharpened for the test at a slightly higher cutting speed on the next inch-length. This sequence of operations was repeated for about fourteen different cutting speeds, these ranging from 7 feet per minute to approximately 125 feet per minute for each test-bar and for each variety of tool-steel experimented with. The character of the finish produced at each speed by each tool was determined as indicated above, and the whole object of these tests was the determination of the manner in which the cutting speed affected the quality of the work done by lathe finishing tools, and especially of any critical cutting speed or speeds which might exist for this type of tool.

Test Results.—The final results of these are given in Tables 1 and 2 (pages 762–3), the former covering the tests on the mild-steel bars, and the latter those on the hard-steel bars. It should be noted that, in every case, these tests were made under ordinary finishing-cut conditions, including the use of a cooling and lubricating agent (diluted soluble-oil compound) and a cutting-edge trail equal to one-half the feed, so as to make the results as applicable to ordinary practice as possible.

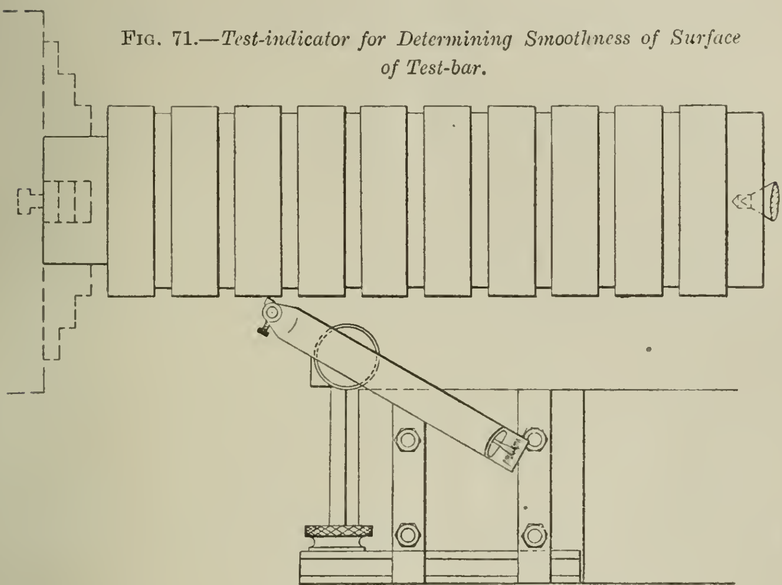
In these Tables (x) indicates the cutting speed at which the phenomenon of building-up on the cutting edge of the tool was observed to be marked under each set of conditions. Probably, the presence of the built-up edge accounts for the formation of the rough, torn surface in each instance.

An examination of these results will show that there is practically no minimum limiting or critical cutting speed, at below which finish-turning operations cannot be satisfactorily performed since, though the lowest cutting speed employed in these tests was 7 feet per minute, the degree of finish obtained at this speed was not inferior to that obtained at any one of the higher speeds, whilst

cutting speeds below this are of little significance from the ordinary workshop view-point.

In regard to the question of the maximum limiting cutting speed for finishing cuts, it will be seen that, for the mild-steel bar, this is in the vicinity of 48 feet per minute for each of three kinds of tool-steel experimented with; whilst, for the hard-steel bar, it varies from 17 feet per minute for the ordinary oil-hardening

Fig. 71.—*Test-indicator for Determining Smoothness of Surface of Test-bar.*



variety of high-speed tool-steel to 28 feet per minute for the water-hardening variety of high-speed tool-steel, plain carbon tool-steel being intermediate to these. Above these respective speeds the tools did not produce surfaces which would pass any acceptable visual test for smoothness, and no evidence could be obtained to show that cutting speeds above these respective limits are suitable for finish-turning operations.

Quantitative Test Methods.—As a check upon the results of the

TABLES 1A–1C.

Results of Finishing-cut Tests on Mild-Steel Test-Bar, W, with Lubricant-coolant.

Depth of Cut = 0·004 *inch.* *Feed per Revolution of Bar* = $\frac{1}{24}$ *inch.*

1A.—*Plain Carbon Tool-Steel.*		1B.—*Ordinary High-speed Tool-Steel.*		1C.—*Superior High-speed Tool-Steel.*	
Cutting Speed.	Character of Finish obtained on Surface of Test-Bar.	Cutting Speed.	Character of Finish obtained on Surface of Test-Bar.	Cutting Speed.	Character of Finish obtained on Surface of Test-Bar.
Feet per min.		Feet per min.		Feet per min.	
7	Smooth	7	Smooth	7	Smooth
10	,,	11	,,	12	,,
15	,,	15	,,	17	,,
20	,,	20	,,	22	,,
25	,,	27	,,	28	,,
31	,,	33	,,	33	,,
38	,,	40	,,	41	,,
48	,,	48	,,	48	,,
58 (x)	Rough (surface torn)	58 (x)	Rough (surface torn)	58 (x)	Rough (surface torn)
71	,,	70	,,	68	,,
84	,,	84	,,	80	,,
96	,,	96	,,	95	,,
109	,,	110	,,	107	,,
119	,,	120	,,	120	,,

TABLES 2A–2C.

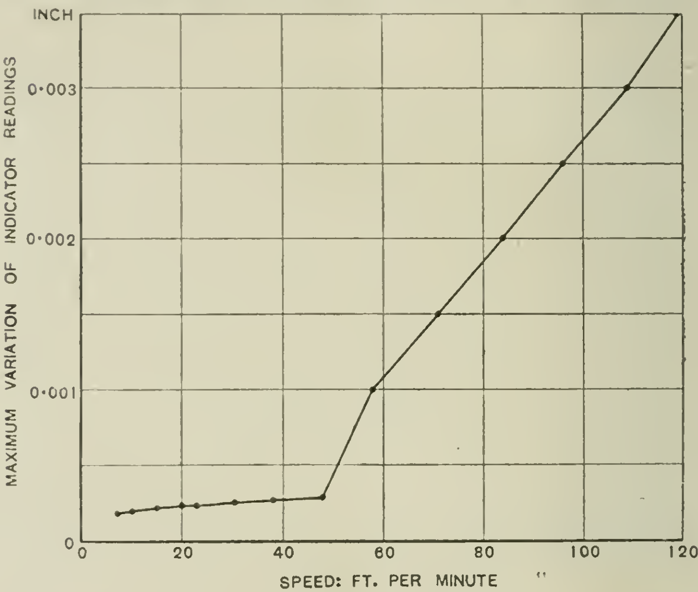
Results of Finishing-cut Tests on Hard-Steel Test-Bar, Z, with Lubricant-coolant.

Depth of Cut = 0·004 *inch.* *Feed per Revolution of Bar* = $\frac{1}{24}$ *inch.*

2A.—*Plain Carbon Tool-Steel.*		2B.—*Ordinary High-speed Tool-Steel.*		2C.—*Superior High-speed Tool-Steel.*	
Cutting Speed.	Character of Finish obtained on Surface of Test-Bar.	Cutting Speed.	Character of Finish obtained on Surface of Test-Bar.	Cutting Speed.	Character of Finish obtained on Surface of Test-Bar.
Feet per min.		Feet per min.		Feet per min.	
7	Smooth	7	Smooth	7	Smooth
12	,,	12	,,	11	,,
16	,,	17	,,	16	,,
21	,,	21 (x)	Rough (surface torn)	21	,,
23	,,	24	,,	28	,,
28 (x)	Rough (surface torn)	30	,,	34 (x)	Rough (surface torn)
33	,,	38	,,	42	,,
38	,,	48	,,	54	,,
54	,,	58	,,	66	,,
64	,,	71	,,	78	,,
76	,,	86	,,	89	,,
86	,,	100	,,	101	,,
97	,,	114	,,	115	,,
106	,,	124	,,	128	,,
116	,,	—	—	—	—

above tests, and to determine, if possible, a quantitative measure of the degree of smoothness of the surface formed at each cutting speed, several other test methods were experimented with, the most successful being the test-indicator method. The method of using the indicator is indicated in Fig. 71 (page 761), the instrument being held in the tool-holder of the lathe slide-rest and moved along like

FIG. 72.—*Relation between Smoothness of Surface and Cutting Speed.*



the tool after the latter had formed the surface. The contact finger of the indicator was placed in contact with the tooled surface of the test-bar, and the maximum variation of the readings of the indicator was observed whilst the latter was traversed from end to end of each inch-length of the bar. This variation was obtained for each of a number of places in the circumference of the bar for each inch-length, and the average maximum variation so obtained for each length was taken as a measure of the general roughness of the surface of that length.

The conditions under which these tests were made were precisely

the same as those of the previous tests, so that the two sets of results are quite comparable. In Table 3 (below) the results of the tests with plain carbon-steel tools made on the mild-steel test bar are given in tabular form, whilst in Fig. 72 the same results are presented in graphical form. The results of the tests with the ordinary and superior high-speed steel tools on both the mild-steel and hard-steel test bars were similar in character to those here given.

TABLE 3.—*Lathe Indicator-Tests.*

Plain Carbon-Steel Tool on Mild-Steel Bar, W.
Depth of Cut. = 0·004 inch. Feed = $\frac{1}{24}$ inch per revolution.

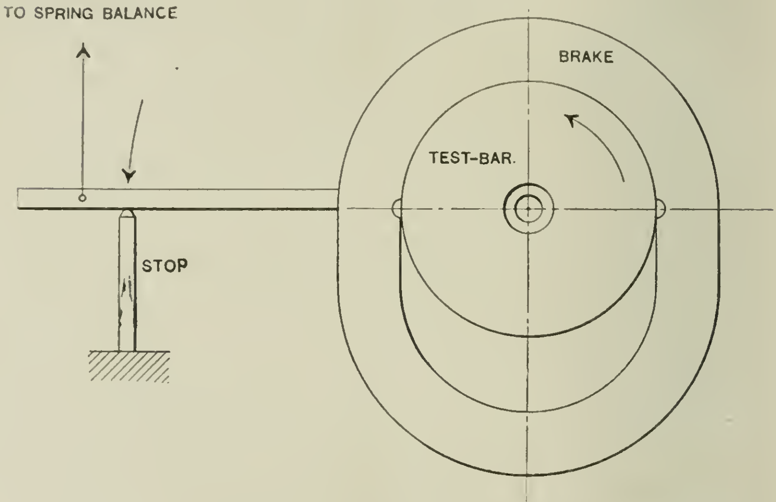
Cutting Speed, in feet per minute.	Average Maximum Variation in Indicator Readings.
7	Under 0·00025 inch.
10	,, ,, ,,
15	,, ,, ,,
20	0·00025 inch.
25	,, ,,
31	,, ,,
38	Slightly above 0·00025 inch.
48	,, ,, ,, ,,
58	0·0010 inch.
71	0·0015 ,,
84	0·0020 ,,
96	0·0025 ,,
109	0·0030 ,,
119	0·0035 ,,

This Table and diagram show that up to a cutting speed of 48 feet per minute the degree of roughness of the surface formed

was practically constant. Between this speed and a cutting speed of 58 feet per minute, however, there occurred a comparatively sudden change in the character of the surface formed, and this change appeared to be maintained regularly as the cutting speed was further increased.

These results confirm the results of the visual-examination tests, and both sets of results indicate that from the standpoint of surface-finish there is no minimum critical cutting speed below which it is not advisable to work a finish-turning tool.

Fig. 73.—*Test-Brake.*



Several other forms of check tests were tried, but these for various reasons, chiefly connected with the conditions peculiar to the tests themselves, had to be abandoned. The majority of these tests involved the use of small friction brakes, which were used in several different ways. In one of these brake tests an attempt was made to measure the frictional resistance between the surface of the test-bar and the working surface of the brake, the underlying idea being that the degree of smoothness of the former was related to this resistance. The arrangement of the brake is indicated in Fig. 73. It was found, however, that either the braking action

produced a slight and gradual change in the character of the surface under test, or the character of the working surface of the brake (which was made variously of lead, copper, hard cast-iron, and hard wood) underwent a gradual change with the progress of the tests. Furthermore, it was impossible to keep the two surfaces perfectly dry and free from moisture and grease, and so prevent the test results from being influenced by lubrication effects.

Another unsuccessful braking method had as its basis the time taken by the brake, under a given constant pressure, to move a definite distance (actually one inch) longitudinally along the test-bar under the influence of the combination of the rotary motion of the bar and the feed marks left by the tool on the surface of the bar. Here, also, the conditions of the test produced changes in the character of the surface under test, thus vitiating the results.

2.—Relation between Cutting Speed and Durability of Lathe Finishing Tools.

Having obtained the values of the cutting speed beyond which it was found impossible to obtain a smooth, finished surface on steel, tests were made to determine the relation between the cutting speed and the durability of lathe finishing tools up to the critical or limiting cutting speeds for the several sets of conditions.

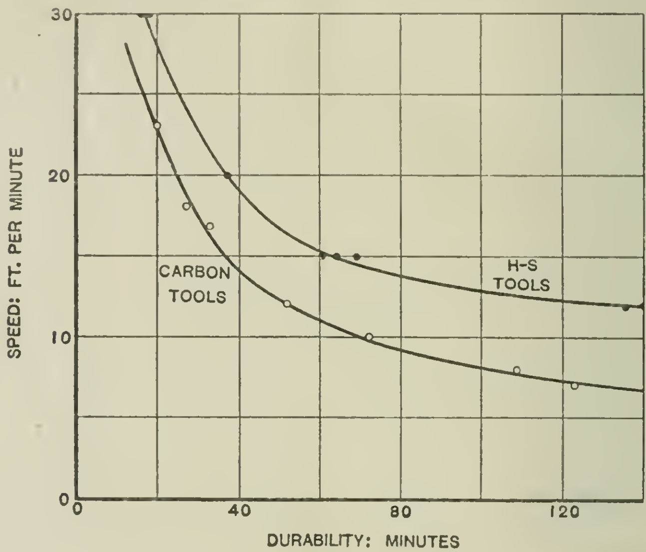
In these tests each tool was worked at a number of graduated cutting speeds ranging up to the limiting speed as determined in the previous tests for the respective conditions; and the durability of its cutting edge was determined at each speed, the durability in this case being taken as the time required from the commencement of the cut to blunt the cutting edge of the tool sufficiently to cause it to be pushed away from the test-bar and thus to lose its cut.

Other methods of determining the durability of the tools were tried, these including test-indicator, screw-micrometer, and visual-examination methods; but the first two of these did not work very satisfactorily for a variety of reasons, whilst it was found that, by means of the visual-examination method, it was not possible to decide just when and where a critical change in the character of

the tooled surface occurred, though the method was suitable for the purposes of comparison in regard to surfaces unconnected and distinct. All these methods were consequently abandoned in favour of the one described above.

The results of two sets of these tests are indicated in graphical form in Fig. 74. The sample curves given in this figure represent

FIG. 74.—*Durability for Finishing Tools.*



the relationships between the durability of plain carbon-steel finishing tools and high-speed steel finishing tools and the cutting speeds on the hard-steel test-bar, Z, the curves for the other combinations of tool-steel and test-bar steel being similar to these in general character.

It will be noticed that the general form of these curves is somewhat similar to that of the durability curves given in the previous Paper * as applying to the case of roughing tools, high durability of the cutting edge being associated with low cutting

* Proceedings, I.Mech.E., 1913, pages 1081 *et seq.* and 1096 *et seq.*

speed, and vice versa; and that there is no decline of durability coinciding with a reduction of the cutting speed, nor an increase of durability coinciding with an increase of the cutting speed.

3.—Influence of Rake Angles of Roughing Tools on Cutting Power.

In the tests described in the previous Paper the tools were all ground to the same angles of rake and clearance so as to reduce the number of variables involved in the work. It was not, however, intended that this should suggest that the angles, particularly of

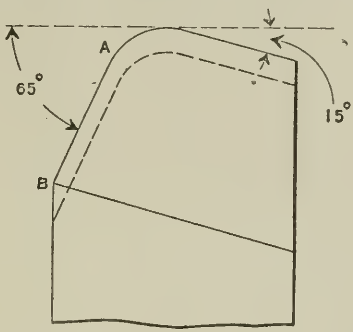


Fig. 75.
Roughing Tool, Plan.

rake, given therein were the most suitable angles to adopt under all circumstances; and further investigations have been made with a view to the determination of the relationship which subsists between the angles of a lathe roughing tool and its cutting power.

These investigations were carried out on the mild-steel, medium-steel, and hard-steel test-bars, A, B, and C respectively, the chemical compositions and physical properties of which are given in Appendixes VII and VIII (pages 821–2).

The tools for this research were made from $\frac{3}{4}$-inch by $\frac{1}{2}$-inch bars of ordinary high-speed tool steel, containing about 14 per cent. of tungsten. The plan-shape of each tool-nose is indicated in Fig. 75, the combination of the front and side rake angles being such as to make the cutting edge AB horizontal in every instance. The tools were ground directly from the plain bar, without any

preliminary forging, the curvature of the nose, to a radius of $\frac{1}{8}$ inch, being finished off to a template. The combinations of rake angles which were adopted are given in Table 4, the clearance angles accompanying these being 5° for the front of the tool and 4° for the side through the series.

TABLE 4.—*Rake Angles of Lathe Roughing Tools.*

No. of Tool.	Front Rake Angle.	Side Rake Angle.
1	0°	0°
2	$2\frac{1}{2}$°	5°
3	$4\frac{1}{2}$°	10°
4	$5\frac{1}{2}$°	12°
5	7°	15°
6	$9\frac{1}{2}$°	20°
7	$12\frac{1}{2}$°	25°
8	15°	30°
9	18°	35°

The test which was applied was the "Speed-increment Test"* as devised for the comparative testing of tool steels. The starting speeds in the tests on the different materials were as follows: on mild steel, 80 feet per minute; on medium steel, 60 feet per minute; and on hard steel, 30 feet per minute. The cut adopted for the whole series of tests was $\frac{1}{8}$ inch deep with a feed of $\frac{1}{12}$ inch per revolution.

Three tests were made with each tool on each test-bar, and the average of the results of the three tests in each case was taken as the criterion value for the particular combination of rake angles and test-bar material, this criterion value, which represents the cutting power, being the average volume of metal, in cubic inches, removed from the test-bar up to the point of breakdown of the

* Proceedings, I.Mech.E., 1913. Page 1119.

Fig. 76.—*Effect of Variable Rake Angles. Mild Steel.*

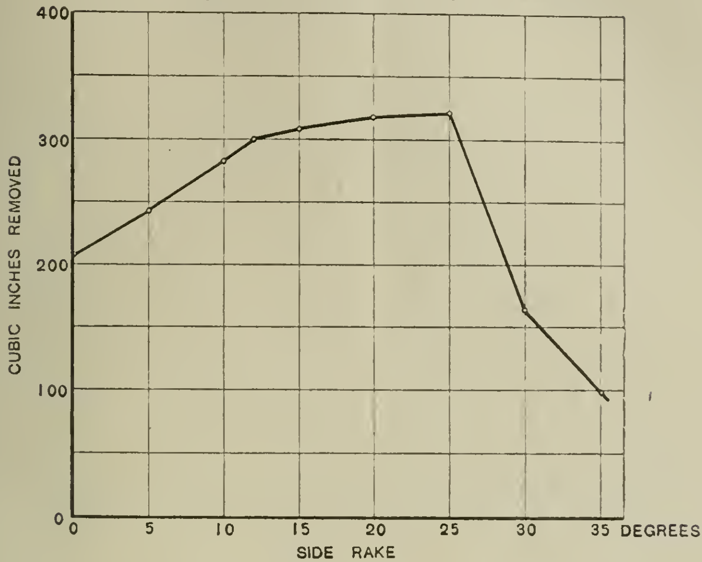
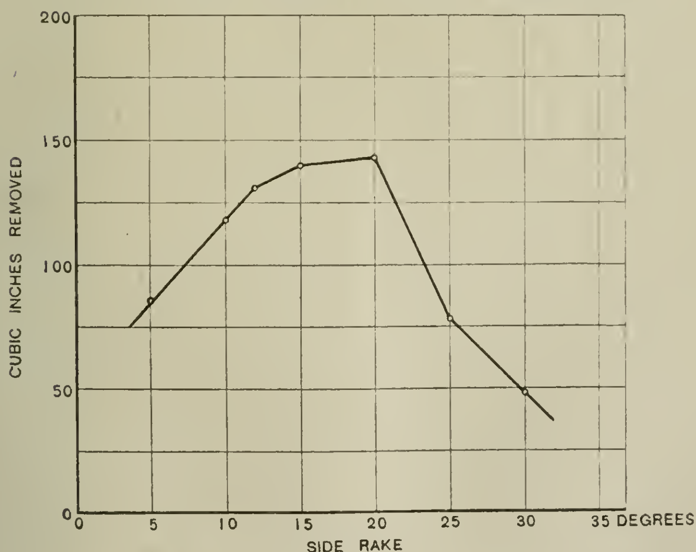


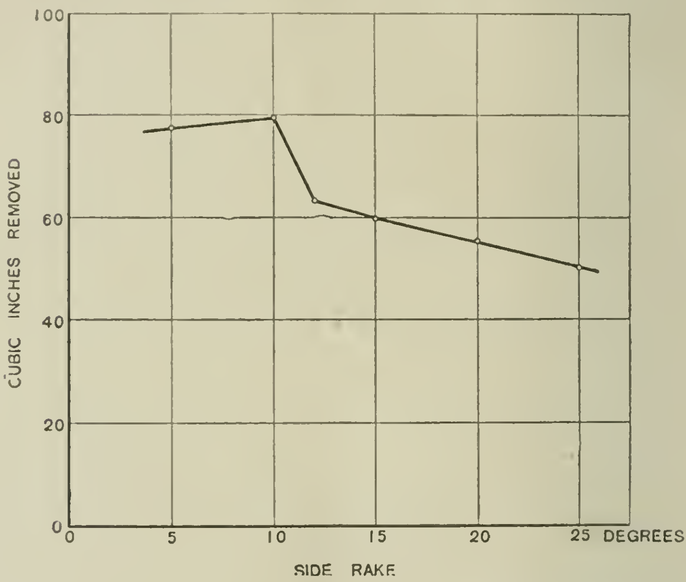
Fig. 77.—*Effect of Variable Rake Angles. Medium Steel.*



cutting edge of the tool. The average results of all the tests in this series are set forth in Tables 5A to 5C (page 775).

These results indicate that, for the machining of the mild-steel bar, the most suitable angle of side rake (that is, the angle of side rake associated with maximum durability and cutting power) lies between 20° and 25°, with a corresponding front-rake angle of 10°–12°, the corresponding angles for the machining of the medium-steel

FIG. 78.—*Effect of Variable Rake Angles. Hard Steel.*



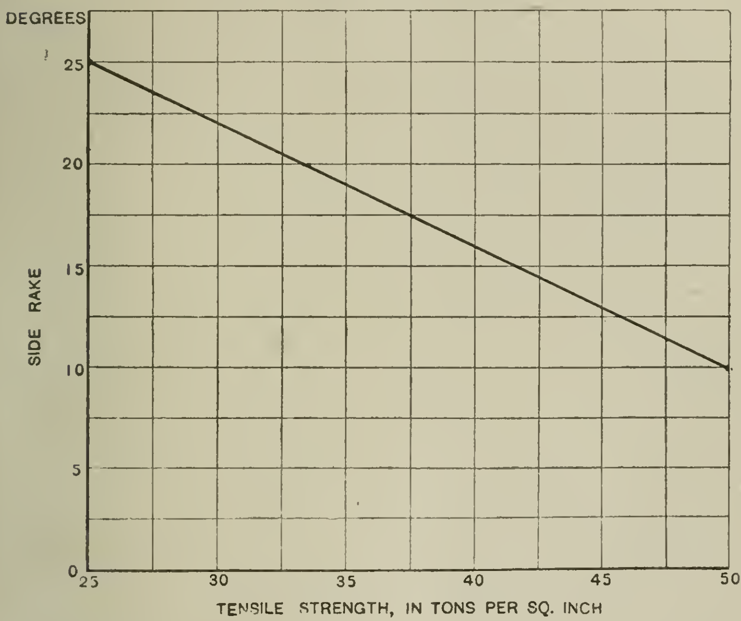
bar being 15°–20° and 7°–9½° respectively, and for the machining of the hard-steel bar 10° and 4½° respectively.

The curves in Figs. 76–78 illustrate these results graphically, and show (1) that there is a critical angle of sharpness of the nose of the tool for each grade of hardness of the material to be machined; (2) that a slight variation in the value of the angle of rake has a relatively small influence on the durability and cutting power of the tool, provided that the variation is in the nature of a reduction of the value; and (3) that when the critical angle of rake is exceeded

there is a very rapid depreciation in the life and cutting qualities of the tool, provided that all the other conditions of working are maintained constant and unvarying.

The relationship between the angle of side rake for the maximum output of the tool (that is, the critical angle of side rake) and the maximum tensile strength of the steel to be machined is indicated

FIG. 79.—*Relation between the Most Suitable Side-rake Angle and the Tensile Strength of Bar Turned.*



in graphical form in Fig. 79, from which it will be seen that the law which connects these two quantities is practically a straight-line law. The equation to the curve is as follows:—

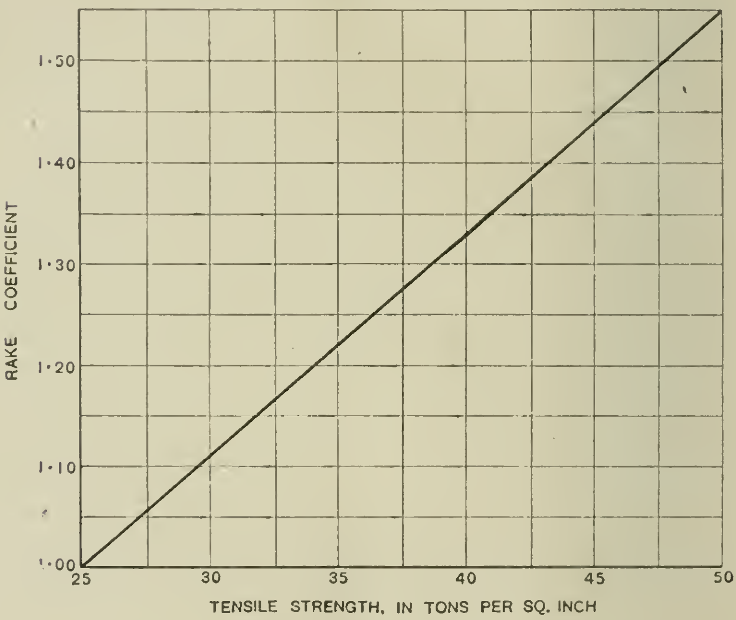
$$R = 40 - 0{\cdot}6\ T, \qquad . \qquad . \qquad . \qquad (1)$$

where R = the critical angle of side rake, in degrees, and T = the maximum tensile strength of the steel operated upon, in tons per square inch.

Relating the results of these tests with the test-results recorded

in the original Paper, we find that the angles of rake adopted throughout the original tests, namely, 23° of side rake and 11° of front rake, are practically those which are the most suitable angles for tools to be used on mild steel, and that the cutting speeds given in that Paper for the rough machining of mild steel are, therefore, confirmed. But in the case of the rough-machining of steel of

FIG. 80.—*Rake—Coefficient Curve.*



medium and hard qualities, the results already recorded, since they are based upon the condition of constant rake angles for all degrees of hardness of the material to be machined, require to be modified and corrected in view of the above results. This modification is necessary because of the fact that with the most suitable angles of rake in each case the cutting power of a tool is much greater than when the uniform standard angles of 23° and 11° are used.

The necessary modification consists of the introduction into

TABLES 5A–5C.

Rake-angle Tests: Cutting Power of Lathe Roughing Tools.

No. of Tool.	5A.—*Speed-increment Tests on Mild-steel Bar, A.* Starting Speed 80 feet per minute. Depth of Cut $\frac{1}{8}$ inch. Feed $\frac{1}{12}$ inch per revolution.				5B.—*Speed-increment Tests on Medium-steel Bar, B.* Starting Speed 60 feet per minute. Depth of Cut $\frac{1}{8}$ inch. Feed $\frac{1}{12}$ inch per revolution.				5C.—*Speed-increment Tests on Hard-steel Bar, C.* Starting Speed 30 feet per minute. Depth of Cut $\frac{1}{8}$ inch. Feed $\frac{1}{12}$ inch per revolution.			
	Average Duration of Test, or Durability of Tool.		Average Volume of Metal Removed by Tool.	Colour of Turning Removed at Beginning of Test.	Average Duration of Test, or Durability of Tool.		Average Volume of Metal Removed by Tool.	Colour of Turning Removed at Beginning of Test.	Average Duration of Test, or Durability of Tool.		Average Volume of Metal Removed by Tool.	Colour of Turning Removed at Beginning of Test.
	min.	sec.	cub. in.		min.	sec.	cub. in.		min.	sec.	cub. in.	
1	20	12	228	Grey	—		—	—	—		—	—
2	21	25	243	Blue	10	28	85	Pale Blue	16	22	77·6	Grey
3	24	31	283	Purple	14	7	118	Blue	16	40	79·5	Pale Blue
4	25	43	301	Dark Brown	15	32	131	Purple	13	47	63·2	Blue
5	26	28	309	Light Brown (Straw Colour)	16	28	140	Dark Brown	13	14	60·1	Purple
6	27	0	319	Colour hardly perceptible	16	43	143	Light Brown (Straw Colour)	12	25	55·5	Dark Brown
7	27	21	322	Uncoloured	9	37	78	Colour hardly perceptible	11	21	50·2	Light Brown (Straw Colour)
8	15	2	164	"	6	5	48	Uncoloured	—		—	—
9	12	9	98	"	—		—	—	—		—	—

the associated-speed formulæ * of a factor which may be very appropriately described as a "rake coefficient," since it represents the enhancement of the cutting power under the above conditions. This rake coefficient is the ratio of the maximum output (that is, the output obtained with the most suitable angles of rake) and the output with the angles of rake adopted in the original tests. The value of this coefficient depends upon the tensile strength of the steel in the test-bar, the relation between these two quantities obeying a straight-line law as is indicated in graphical form in Fig. 80. From this figure it will be seen that the value of the rake coefficient when the tensile strength is 25 tons per square inch is 1·00, and that it is 1·55 when the tensile strength is 50 tons per square inch. The expression which is represented by the curve in this figure is :—

$$\begin{aligned} C_r &= 0\cdot45 + 0\cdot022\,T \\ &= 0\cdot022\,(20 + T) \text{ practically}, \end{aligned} \qquad (2)$$

where C_r = the rake coefficient, and T = the tensile strength of the test-bar steel, in tons per square inch.

The associated-speed formula for plain carbon-steel turning tools, assuming the use of the most suitable angles of rake as given in Fig. 79 (page 773), becomes by the introduction of the above rake coefficient :—

$$S = \frac{0\cdot00077\,(67 - T)\,(20 + T)\,\sqrt[4]{a}}{\sqrt{F\,D}} \qquad (3)$$

The corresponding formula for high-speed steel turning tools is :—

$$S = \frac{0\cdot00537\,(65 - T)\,(20 + T)\,\sqrt[6]{a}}{\sqrt[3]{F^2\,D}} \qquad (4)$$

In these two formulæ, S = the associated cutting speed, in feet per minute; T = the tensile strength of the steel to be turned in tons per square inch; a = the cross-sectional area of the shank of the tool, in square inches, with the nose-radius a function of the cross-section; F = the feed of the tool per revolution of the work piece; and D = the depth of cut to be taken by the tool.

The above two formulæ are deduced from the results of tests in

* Proceedings, I.Mech.E., 1913, Part 4, page 1207.

which no lubricant or coolant was employed on the tools or test-bars. They, therefore, represent the case of "dry" rough turning. The formulæ for "wet" or "lubricated and cooled" rough turning can be derived from these by applying a correction obtained by averaging the gains of cutting power secured by using a lubricant-coolant as given by the results of tests made later with wet turning. This average gain is practically 50 per cent., so that the associated-speed formula for ordinary carbon-steel turning tools, assuming the use of the most suitable angles of rake, as given in Fig. 79 (page 773), and the use of an effective lubricant-coolant, is:—

$$S = \frac{0\cdot00115\,(67 - T)\,(T + 20)\,\sqrt[4]{a}}{\sqrt{F D}} \qquad . \qquad . \qquad (5)$$

whilst the corresponding formula for high-speed turning tools is:—

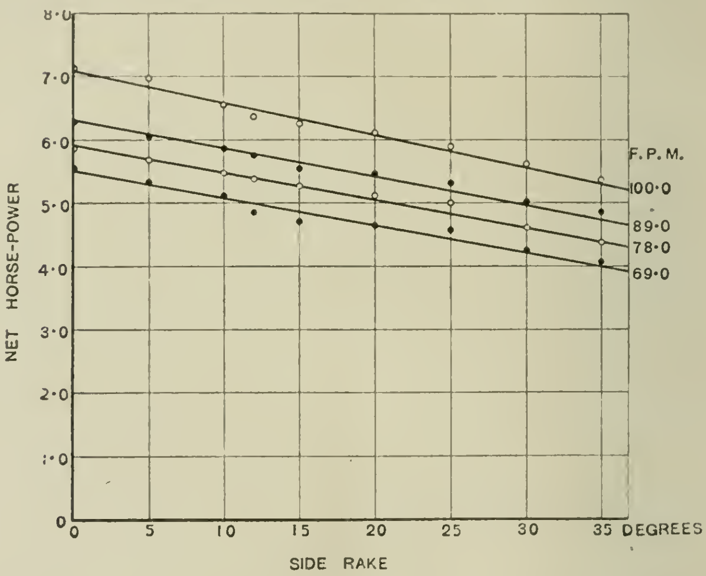
$$S = \frac{0\cdot00805\,(65 - T)\,(T + 20)\,\sqrt[6]{a}}{\sqrt[3]{F^2 D}} \qquad . \qquad . \qquad (6)$$

Another point which these results bring out is that the colour of the turnings which are formed when steel is being machined in the lathe depends upon the degree of hardness of the steel and the rake angles of the tool. Thus, in the case of mild-steel turning, an uncoloured or only faintly coloured cutting is formed when the tool is ground with the most suitable angles of rake; and with a reduction in these angles the colour of the cutting deepens until a limiting grey is reached. In the case of medium-steel turning the most suitable rake angles are associated with a brown colour of chip; whilst the corresponding colour in the case of hard-steel turning is a pale blue. These differences are probably due to the fact that the hardness of steel is dependent to a considerable extent upon its carbon content, and that the oxygen of the atmosphere unites more readily with the carbon to produce discoloration in the case of the steel with the higher carbon-content, especially at the higher chip temperatures which are attained in this case. It would, therefore, appear that the colour of the chips formed in a rough-turning operation is not necessarily an index of the condition of maximum cutting efficiency, as is frequently supposed.

4.—Relation between Rake Angles and Power Consumption of Lathe Roughing Tools.

As an addendum to the above tests, an investigation was made into the influence of the angles of rake of a lathe rough-turning tool upon the power actually expended at the cutting edge of the tool in overcoming the cutting resistances. These tests were made with the afore-mentioned tools (Table 4, Nos. 1–9), on the same test-bars, A, B, C, and with the same area of cut, $\frac{1}{8}$ inch deep by $\frac{1}{12}$ inch

Fig. 81.—*Relation between Side-rake Angle and net Horse-power Consumed by Roughing Tool, Mild-Steel Bar.*



feed per revolution, the form of test adopted being the so-called constant-speed test. Each tool was worked at four different cutting speeds, as given in Table 6A–6C, the speed throughout each individual test being maintained as constant as possible. In these Tables, the net horse-power expended in overcoming the resistances at the cutting edge of the tool is given for each combination of tool, test-bar, and cutting speed, this quantity being the calculated

TABLES 6A–6C.

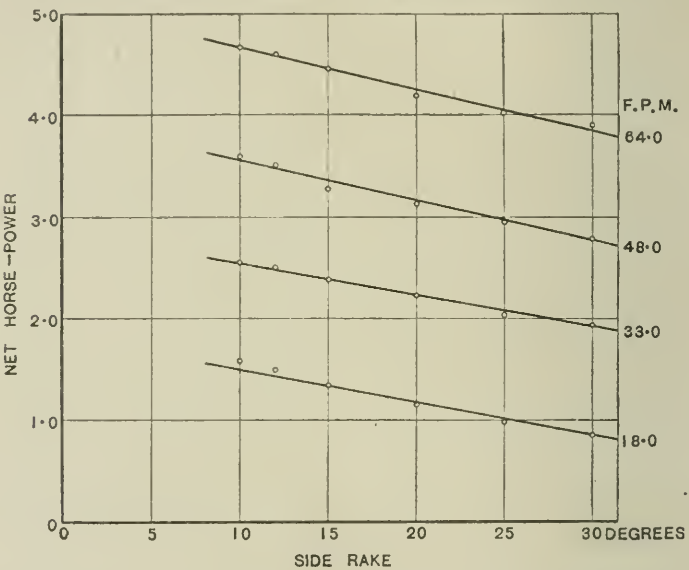
Rake-angle Tests: Net Power Consumption of Lathe Roughing Tools.

No. of Tool.	6A.—*Tests on Mild-Steel Bar, A.* Depth of cut $\frac{1}{8}$ inch. Feed $\frac{1}{12}$ inch per rev.		6B.—*Tests on Medium-Steel Bar, B.* Depth of Cut $\frac{1}{8}$ inch. Feed $\frac{1}{12}$ inch per rev.		6C.—*Tests on Hard-Steel Bar, C.* Depth of Cut $\frac{1}{8}$ inch. Feed $\frac{1}{12}$ inch per rev.	
	Cutting Speed.	Net Horse-power consumed at Nose of Tool.	Cutting Speed.	Net Horse-power consumed at Nose of Tool.	Cutting Speed.	Net Horse-power consumed at Nose of Tool.
	Feet per min.		Feet per min.		Feet per min.	
1		5·58		—		—
2		5·38		1·64		1·92
3		5·17		1·57		1·74
4		4·85		1·50		1·71
5	69·0	4 70	18·0	1·34	19·9	1·58
6		4·63		1·15		1·42
7		4·55		0·98		1·39
8		4·23		0·85		—
9		4·06		—		—
1		5·91		—		—
2		5·71		2·70		2·87
3		5·49		2·54		2·81
4		5·38		2·50		2·74
5	78·0	5·26	33·0	2·38	30·9	2·57
6		5·10		2·22		2·40
7		5·00		2·03		2·23
8		4·61		1·93		—
9		4·31		—		—
1		6·25		—		—
2		6·06		3·72		4·11
3		5·86		3·60		3·87
4		5·74		3·50		3·69
5	89·0	5·54	48·0	3·27	41·0	3·55
6		5·47		3·13		3·41
7		5·31		2·95		3·23
8		5·01		2·80		—
9		4·86		—		—
1		7·11		—		—
2		6·97		4·85		4·62
3		6·53		4·67		4·46
4		6·36		4·60		4·31
5	100·0	6·25	64·0	4·46	46·2	4·00
6		6·10		4·18		3·69
7		5·90		4·03		3·50
8		5·61		3·90		—
9		5·45		—		—

difference between the gross horse-power required to run the lathe against the cut, and the horse-power required to run the lathe with the slide-rest in motion at the same rate of transverse, but without the cut.

These results (which are presented in graphical form in Figs. 81–83) show that in every case an increase in the angles of rake is accompanied by a decrease in the net rate at which energy is

FIG. 82.—*Relation between Side-rake Angle and net Horse-power Consumed by Roughing Tool, Medium-Steel Bar.*

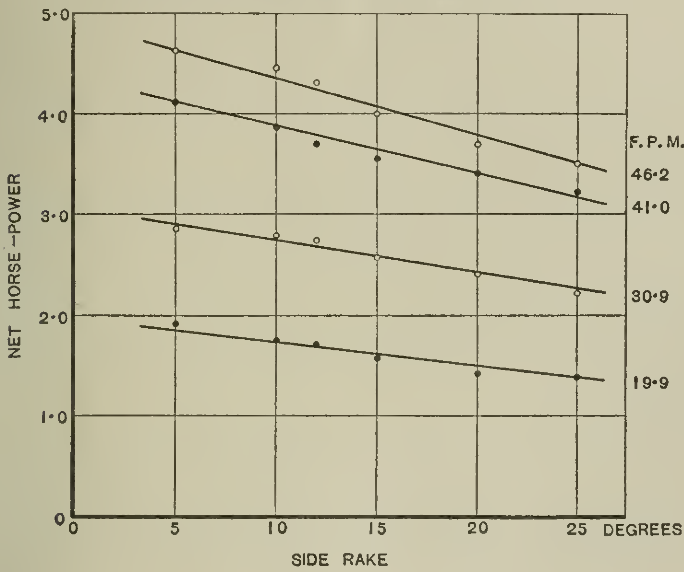


consumed at the nose of the tool to overcome the resistance to cutting offered by the material being cut. From this we may draw the deductions that with an increased amount of rake a lathe turning tool cuts more readily and freely, and that there are no critical values of the angles of rake in connexion with the net power consumption as there are in connexion with the durability of the cutting edge of such a tool. Thus, whilst a side-rake angle of 10° is associated with the maximum durability of the cutting edge of the tool when hard steel is being turned, it is not associated

with either the minimum or the maximum net power-consumption. This also applies to a side-rake angle of 20° for medium-steel turning, as well as to one of 25°, for mild-steel turning.

One conclusion which follows directly from this result is that the durability of the cutting edge of a lathe rough-turning tool does not depend solely upon the rate at which heat is generated in the

Fig. 83.—*Relation between Side-rake Angle and net Horse-power Consumed by Roughing Tool, Hard-Steel Bar.*



process of cutting; but also upon the form and general dimensions of the nose of the tool.

5.—Influence of Nose-Radius and Tool Section Cutting Qualities of Lathe Roughing Tools.

In the previous Paper,* the results of an investigation on lathe turning tools of different sectional dimensions were given, the object of the investigation being to determine the relation between

* Proceedings, I.Mech.E., 1913, page 1111.

the output and sectional area of a lathe turning tool under special conditions. In the experiments involved in the investigation, the effect of varying the radius of the cutting edge of the tool was not separated from the effect of varying the section of the shank or body of the tool, since all the tools tested were prepared with cutting edges of the same geometrical shape, the nose-radius in each case being distinctly proportional to the sectional dimensions of the tool.

A further research has since been made with a view to the determination of the individual effect of each of these two factors, and also of their mutual relation, as well as to show whether the cutting efficiency of a lathe roughing tool is dependent at all upon its sectional dimensions.

The tools which were experimented with were made of the ordinary quality of high-speed steel and ground from the plain bar on a universal tool-grinding machine, the sections of the tools ranging from $\frac{1}{2}$ inch square to $1\frac{1}{4}$ inch square as in the previous experiments. The shape of nose adopted for these tools was the one taken as the standard in the original tests, the plan view of which is given in Fig. 75 (page 769), the angles of the tool being as follows:—

Top rake, front	$= 11°$.	Front or heel clearance	$= 5°$.
,, ,, side	$= 23°$.	Side clearance	$= 5°$.

In these experiments, the speed-increment test was applied in two forms: the first involving a constant life of the tool, or constant test-duration, of twenty minutes with a variable depth of cut; and the second a constant depth of cut and constant feed with a variable life of the tool.

In the first set of experiments, which embodied the first form of the speed-increment test, and which were made on the hard-steel bar, C, a starting speed of 20 feet per minute was adopted, and a speed-increment of 1 foot per minute was applied every minute. With each tool it was found possible to select depths of cut which would give, with a given constant feed, test-durations or tool-lives of tweny minutes, slightly more or less; and the depth of cut which corresponded to the standard tool life of twenty minutes was

obtained by interpolation in a curve drawn from the data of a number of such tests and equating the experimental depth of cut with the actual life of the tool.

The results of these tests and determinations, in which a constant feed of $\frac{1}{12}$ inch was maintained, are given in Table 7.

TABLE 7.

Tool-Section and Nose-Radius Tests on Hard-Steel Bar, C.

Speed-increment Tests, starting at 20 feet per minute with $\frac{1}{12}$ inch feed.

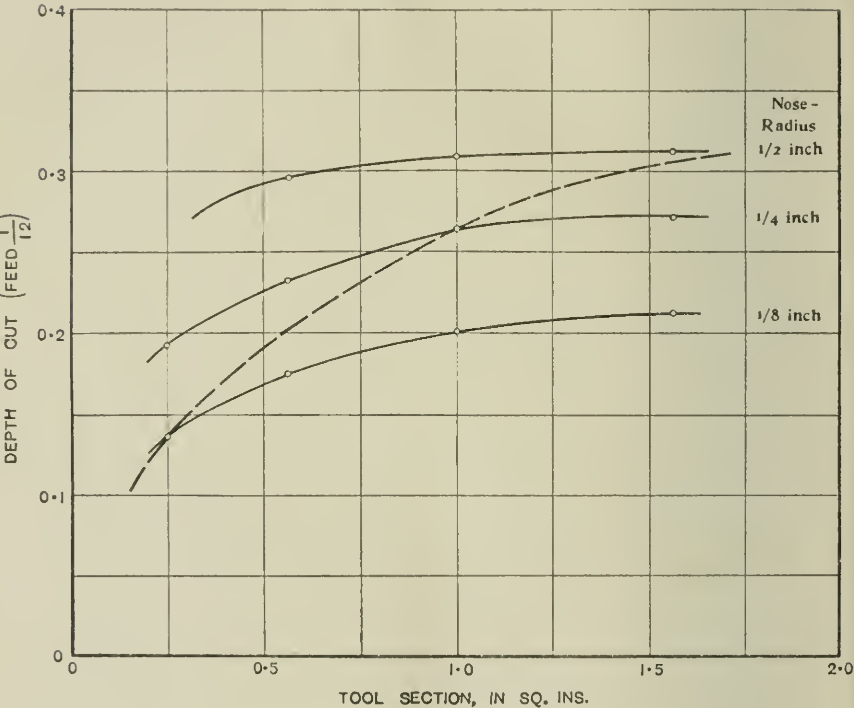
Section of Tool-Steel.	Depth of Cut corresponding to Standard Tool-Life of 20 mins.		
	Nose-radius = $\frac{1}{8}$ in.	Nose-radius = $\frac{1}{4}$ in.	Nose-radius = $\frac{1}{2}$ in.
Inch.	Inch.	Inch.	Inch.
$\frac{1}{2} \times \frac{1}{2}$	0·137	0·193	—
$\frac{3}{4} \times \frac{3}{4}$	0·175	0·232	0·296
1×1	0·201	0·265	0·307
$1\frac{1}{4} \times 1\frac{1}{4}$	0·211	0·272	0·311

These results are exhibited graphically in Fig. 84 (page 784), from an examination of which it will be seen that the cutting capability of a lathe roughing tool, under conditions which embody a constant average cutting speed, a constant life of the tool, and a correspondingly variable depth of cut, does depend somewhat on the area of section of the tool-steel as well as upon the radius of the cutting edge of the tool. It should be observed, however, that the effect of an increase in the sectional dimensions of the tool-steel is more pronounced with a small cutting-edge radius than it is with a large one, as the following deductions from the above result show :—

Radius of Nose.	*Superiority of $1\frac{1}{4}$ inch Square Tool over $\frac{3}{4}$ inch Square Tool.*
$\frac{1}{8}$ inch	21 per cent.
$\frac{1}{4}$,,	17 ,, ,,
$\frac{1}{2}$,,	5 ,, ,,

From these deductions and the character of the curves in the above figure, it is quite conceivable that there is a cutting edge or nose-radius which is associated with no variation of cutting capability when the section of the tool-steel is either increased or reduced. Generally, however, under the above conditions of

FIG. 84.—*Effect upon Output of Cross Sectional Area of Tool-Steel and Nose-radius of Tool.*



cutting speed, life of tool, and depth of cut, the section of the tool-steel, as well as the radius of the cutting edge, is a factor in the cutting power of a lathe roughing tool. At the same time it should be pointed out that there does not appear to be any even comparatively simple relationship between the depth of cut, the area of section of the tool-steel, and the radius of the cutting edge,

when a constant average cutting speed and a constant feed are adopted.

As a matter of general interest, it may be pointed out that the dotted curve in Fig. 84 is a curve for the case in which the radius of the cutting edge is proportional to the square root of the sectional area of the tool-steel, the $\frac{1}{2}$ inch square tool being taken as the basic tool. It is thus similar to the curve which is given in Fig. 40 of the original Paper.*

In the second series of experiments, in connexion with which the second form of the speed-increment test was adopted, tests were made on the mild-steel and hard-steel test-bars, designated A and C respectively. In the tests on the mild-steel bar, the starting speed selected was 90 feet per minute with a speed-increment of 1 foot per minute per minute. For each test the depth of the cut was maintained constant at $\frac{5}{32}$ inch, and the feed constant at $\frac{1}{12}$ inch per revolution. Tools of three sections were used in the tests, these sections being $\frac{1}{2}$ inch square, $\frac{3}{4}$ inch square, and $1\frac{1}{4}$ inch square. Three cutting-edge radii were adopted, namely, 0, $\frac{1}{8}$ inch, and $\frac{1}{4}$ inch, the tools which had a cutting-edge radius of 0 being, of course, ground to a sharp point.

In these tests each tool was worked until its cutting edge completely broke down, and the volume of material removed from the test-bar by the tool under such conditions was taken to be a criterion of the cutting capabilities of the tool. The durations of the tests representing the different conditions and the average cutting speeds and outputs for the different tools were found to be all different, as is shown in the following Table, wherein are summarized the results of these tests, each of these results being the average of the results of four individual tests.

The starting speed selected for the tests on the hard-steel bar was 30 feet per minute, the speed-increment was 1 foot per minute, the depth of cut, which was maintained constant, was $\frac{1}{8}$ inch, whilst the feed, which was also maintained constant, was $\frac{1}{12}$ inch per revolution. In these tests, only two cutting-edge radii were made

* Proceedings, I.Mech.E., 1913, page 1113.

TABLE 8.

Tool-section and Nose-radius Tests on Mild-Steel Bar, A.

Speed-increment Test with Constant Depth of Cut.

Section of Tool-Steel.	Radius of Nose of Tool = 0	⅛ inch.	¼ inch.
	Average Life of Tool, in Minutes and Seconds.		
½ inch square	15 30	19 50	23 25
¾ ,, ,,	17 10	22 52	26 40
1¼ ,, ,,	20 52	28 20	31 30
	Average Output of Tool, in Cubic Inches of Metal.		
½ ,, ,,	247	310	373
¾ ,, ,,	267	363	432
1¼ ,, ,,	328	461	521
Superiority of 1¼ inch square tool over ½ inch square tool . .	23 per cent.	27 per cent.	23 per cent.

use of, these being ⅛ inch and ¼ inch, it being found that the cutting edge with a sharp angular point did not break down in the same manner as did the cutting edges which were more or less curved, so that it was very difficult to determine the precise point of breakdown of the cutting edge in such a case. Four tool sections were used in these tests, these ranging from ½ inch square to 1¼ inch square, and the general conditions of the tests were the same as in the tests on the mild-steel bar. The results of the tests are tabulated below in Table 9, each result given being the average of the results of four individual tests. Regarding the results of these

individual tests it may be stated that the variations amongst them for each particular set of conditions were not very great, the maximum variation observed being of the order of 15 per cent.

TABLE 9.

Tool-Section and Nose-Radius Tests on Hard-Steel Bar, C.

Speed-increment Test with Constant Depth of Cut.

Section of Tool-Steel.	Radius of Nose of Tool = 1/8 inch.	Radius of Nose of Tool = 1/4 inch.
	Average Life of Tool, in Min. and Sec.	
1/2 inch square	11 12	15 32
3/4 " "	12 8	16 33
1 " "	12 39	17 13
1 1/4 " "	12 58	17 36
	Average Output of Tool, in Cub. In. of Metal.	
1/2 inch square	49·3	72·7
3/4 " "	54·3	78·3
1 " "	56·9	82·7
1 1/4 " "	58·8	85·0
Superiority of 1 1/4 inch square tool over 3/4 inch square tool.	8·3 per cent.	8·6 per cent.

A comparison of the results contained in Tables 7, 8, and 9 will show that, when the average cutting speed and the life of the tool are constant quantities, the superiority of the tool with the larger section is generally greater than when the depth of cut is the constant quantity, it being roughly twice as great in the former case as in the latter. It will be further seen that this superiority due to increased sectional dimensions of the tool falls off considerably in the first case when the radius of the cutting edge is increased,

whereas in the latter case this superiority appears to have a fairly constant value.

Regarding the influence of variations in the radius of the cutting edge upon the output or efficiency of a lathe roughing tool, it will be seen that this is much more considerable proportionately than the influence of variations of the sectional dimensions of the tool-steel. Thus, with an increase of the radius of the cutting edge from $\frac{1}{8}$ inch to $\frac{1}{4}$ inch, the improvement in the cutting efficiency of the tool varies from 14 per cent to 48 per cent, according to the general conditions, the higher values of this improvement being associated with the tools having the smaller sections.

6.—Influence of Height of Cutting Edge upon Cutting Efficiency of Turning Tools.

The question of the position of the cutting edge of a lathe turning tool with respect to the centre of the work-piece or test-bar upon which the tool is working, is one of the several questions which enter into the larger problem of general turning-tool efficiency. Concerning this point, however, there does not appear to be a consensus of opinion amongst those to whom the question is of importance. In many quarters it is the practice to arrange the cutting edge or point of a lathe turning tool above the horizontal plane which passes through the axis of rotation of the work-piece; in other instances, the cutting edge or point of the tool is disposed in this plane; whilst in some few cases, it actually falls below this plane.

In the majority of cases wherein the practice of placing the cutting edge or point of the tool above the central horizontal plane is adopted, it is apparently for the assumed reason that the strength of the nose of the tool to resist fracture is thereby increased, the question as to whether this, incidentally or otherwise, affects the cutting power of the tool not being taken into account at all.

To determine this latter point, that is, whether the cutting power of a lathe turning tool is influenced by the position of its cutting edge or point with respect to the axis of rotation of the

work-piece, several series of experiments which are described below were undertaken.

In the first series of experiments, all the tools, which were made of ordinary non-vanadium high-speed steel, were ground and hardened exactly alike, the shape of nose selected being the standard shape already described on page 769, whilst the angles ground on the tools were as follows :—

Top rake, front = 11°. Front or heel clearance = 5°.
" " side = 23°. Side clearance = 4°.

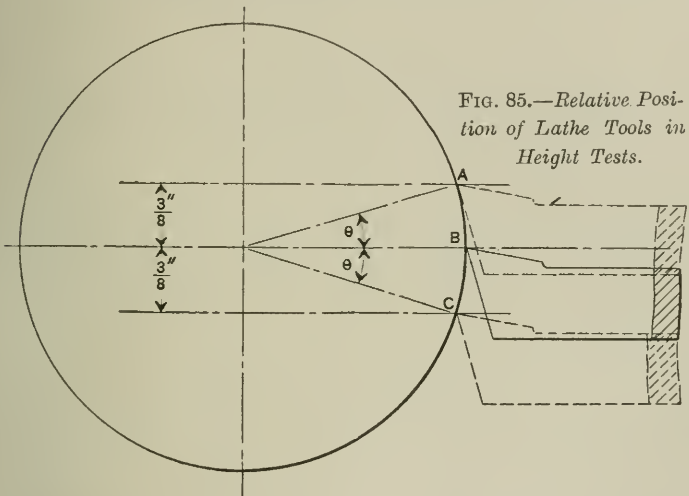


FIG. 85.—*Relative Position of Lathe Tools in Height Tests.*

The tools were $\frac{3}{4}$ inch by $\frac{1}{2}$ inch in section, and the test-bar on which the experiments were made was the mild-steel bar, A. The test adopted was of the constant-speed type, the involved variable being the duration of the test or the life of the tool. The cutting speed selected was 147 feet per minute, with a depth of cut of $\frac{1}{8}$ inch and a feed of $\frac{1}{12}$ inch per revolution. Three positions of the cutting edges of the tools were experimented with, these being as follows :—

1. $\frac{3}{8}$ inch above the central horizontal plane (A, Fig. 85).
2. In this plane (B, Fig. 85).
3. $\frac{3}{8}$ inch below this plane (C, Fig. 85).

The mean diameter of the test-bar was 10·062 inches, so that the angle (θ, Fig. 85) between the line joining the centre of the bar and the cutting point of the tool in each of the first and third positions and the central horizontal plane was about $4\frac{1}{2}°$. The three operative front clearance angles were, therefore, $\frac{1}{2}°$, $5°$, and $9\frac{1}{2}°$ respectively, and the corresponding operative front-rake angles were $15\frac{1}{2}°$, $11°$, and $6\frac{1}{2}°$ respectively.

The results of these tests are given in Table 10, each of these results being the average for four individual tests.

TABLE 10.

Cutting-edge Height Tests on Mild-Steel Test-Bar, A.

Variable Operative Clearance and Rake Angles.

Position of Cutting Edge of Tool.	Average Cutting Speed.	Area of Cut. Depth × Feed.	Average Life of Tool.	Average volume of Metal Removed by Tool.	Average net Power Consumed at Nose of Tool.
	Feet per Minute.	Inch.	Min. Sec.	Cub. In.	H.P.
$\frac{3}{8}$ in. above centres	147	$\frac{1}{8} \times \frac{1}{12}$	8 11	150·4	9·24
On centres . .	,,	,,	7 54	145·2	9·51
$\frac{3}{8}$ in. below centres	,,	,,	4 17	99·1	9·75

In each case the net power consumed at the nose of the tool is the difference between the power consumed with the cut in and that consumed with the cut out, the general conditions being otherwise the same in the two cases.

These results indicate that, with a constant tool angle, there is a slight gain to be secured by raising the cutting edge of the tool slightly above the lathe centres or the axis of rotation of the work-piece, both from the point of view of the durability of the cutting edge of the tool and that of the net power-consumption. In these

tests, the actual improvement in the durability and cutting efficiency of the tool was about $3 \cdot 5$ per cent, and the reduction in the net amount of power consumed by the tool was about 3 per cent, two amounts which are quite comparable.

On the other hand, the above results show that, when the cutting edge of the tool is placed below the centres of the lathe, a depreciation in the durability and cutting qualities of the tool ensues, whilst the net amount of power consumed is simultaneously increased, though not proportionately.

The above net power-consumption phenomena may be due to the differences in the operative angles of top rake, the tools which were disposed with their cutting edges above the lathe centres having the largest operative rake angles and, therefore, cutting more freely than the others. This case is not, however, quite identical with that wherein tools with different angles of rake ground on them are all placed with their cutting edges in the central horizontal plane, since in this latter case the tool angles of such tools would vary and the cross-sectional areas of their noses, one of the factors in the conduction of heat away from the cutting edges, would also all be different, whilst the operative clearance angles would all be equal.

In the second set of experiments, those tools whose cutting edges were to be placed above the lathe centres, had an enhanced amount of clearance *ground* on them to allow for the curvature of the test-bar, and thus to make the operative clearance angle equal to that of the tools disposed normally with respect to the bar. For the same reason, those tools which were to have their cutting edges placed below the lathe centres had a reduced amount of clearance *ground* on them. One of the conditions of these tests was, therefore, the maintenance of a constant operative clearance angle. The tools were all ground alike on the lip or upper surface, so that the tool angle was a variable quantity, since its value depended upon the amount of clearance ground on the tool in each case.

These tests were made on the hard-steel test-bar, C, with tools of the ordinary high-speed quality $1\frac{1}{4}$ inch square in section. Each tool was ground with 6° of front top rake and 12° of side rake,

whilst the clearance angles ground on the tools were as follows:—

Disposition of Cutting Edge of Tool.	*Clearance Angle Ground on Tool.*
1. Above the lathe centres.	10°
2. On ,, ,, ,,	5°
3. Below ,, ,, ,,	0°

Hence, since the vertical distances between the lathe centres and the cutting edges of the tools in positions 1 and 3 were $\frac{5}{16}$ inch throughout, and the mean diameter of the test-bar was 8 inches, the operative angle of clearance in each case was about 5°.

The type of test adopted in this case was the constant-speed test, the duration of the test, or the life of the tool, being taken as the criterion value in regard to the cutting capabilities of the tool. The cutting speed selected was 42 feet per minute, with an area of cut of $\frac{1}{4}$ inch deep by $\frac{1}{12}$ inch feed throughout, this area of cut being maintained as constant as possible.

The average results of these tests are given in Table 11 (page 793), each result given therein being the average of the results of four individual tests distributed as evenly as possible over the length of the test-bar, so as to average out the effects of any possible variations in the texture of the test-bar.

These results show that with a constant operative clearance angle a slight loss in durability follows the raising of the cutting edge of the tool above the lathe centres, the loss in this case being about 6 per cent. On the other hand, the net power consumption shows a reduction when the cutting edge is raised, the gain in this direction being of the order of 7 per cent, and due to the increase in the operative rake angles.

In connexion with the position of the cutting edge of the tool below the lathe centres, it will be seen that the durability is considerably less than when the tool is in its normal position, whilst the net power consumption is a little greater, a result which is identical with that obtained in the first series of tests.

Other sets of tests were made with tools of large and small

TABLE 11.

Cutting-edge Height Tests on Hard-Steel Test-Bar, C.

Constant Operative Clearance and Variable Top-Rake Angles.

Position of Cutting Edge of Tool.	Average Cutting Speed.	Area of Cut. Depth × Feed.	Average Life of Tool.	Average volume of Metal Removed by Tool.	Average net Power Consumed at Nose of Tool.
	Feet per Min.		Min. Sec.	Cub. In.	
$\frac{5}{16}$ in. above centres .	42	$\frac{1}{4}$ in. × $\frac{1}{12}$ in.	7 6	74·6	6·44 h.p.
On centres.	,,	,, ,,	7 32	79·1	6·93 ,,
$\frac{5}{16}$ in. below centres .	,,	,, ,,	3 50	40·2	7·13 ,,

section, and with various shapes of nose, on both the mild- and hard-steel bars, but in every case results similar to the above were obtained.

7.—Influence of Forging Operation on Cutting Power of Lathe Roughing Tool.

The shape of nose of the tool which was adopted as the standard in the original investigations is such that it can be obtained from the plain bar by the single process of grinding, but in the case of the majority of shapes of nose it is necessary to have the nose shaped initially by forging or smithing and finished by grinding. It appeared desirable, therefore, to determine whether this initial forging operation had any influence—deleterious or otherwise—on the cutting qualities of lathe turning tools.

In this determination, tests were made on the mild- and hard-steel test-bars, A and C respectively, with both plain carbon and ordinary high-speed steel tools, the forged tools being finish-ground and hardened exactly like the unforged ones. The speed-increment form of test was applied, the average speed-increment being 1 foot per minute throughout the whole series of tests. The starting

speeds, areas of cut, and other data are given in the following Tables in which the results of the tests are also given, these being in the form of averages. The shape of tool-nose selected was the standard one already described, the side and front rake angles being 12° and 6° respectively for the tools on the hard bar, and 23° and 11° respectively for the tools on the mild bar, with a uniform clearance angle of 5°.

These results demonstrate that there is no appreciable difference between the cutting power of a forged turning tool and that of a similar unforged one, provided that both tools are made of the same kind of steel and pass through the same hardening process.

This conclusion has been confirmed by results obtained incidentally from an extensive investigation which was made on tool-steels as a special war research in the University of Sheffield. In this investigation nearly 1000 individual tests were made on 332 tools of similar shapes under identical conditions, one-half of this number having forged noses, and the other half unforged ones. An analysis of the results of the investigation shows that the two kinds were fairly evenly divided, practically one-half of the tools of each kind giving results above the mean, and the other half below, with an average superiority of not quite 0·25 per cent in favour of the forged tools.

8.—Influence of Direction of Cutting Edge on Net Power Consumption involved in Turning Steel.

In the previous Paper it was shown that the results of actual experiments indicated that the life or durability of a lathe turning tool was dependent to some extent upon the length of the part of the cutting edge in action. That is, the shape and disposition of the cutting edge are amongst the factors which influence the life of a turning tool, the experimental results demonstrating the fact that, by bringing the cutting edge of a tool more nearly parallel to the axis of the test-bar or work-piece and so, for any given depth of cut, increasing the length of the active part of the cutting edge, the life of the tool is increased.

To amplify these results, further lathe tests have been made

with a view to the determination of the influence of the direction and active length of the cutting edge of a tool upon the net power consumed in turning steel.

For the purposes of these tests, twelve high-speed tools, each of a section $1\frac{1}{4}$ inch square, were prepared. These were divided into six sets, of two tools each, the tools of each set having a plan shape of nose peculiar to that set. The general plan shape of the tool-noses is given in Fig. 86, the cutting edge *ab* being arranged in the various sets of tools at the angles given in Table 14 (page 798) and

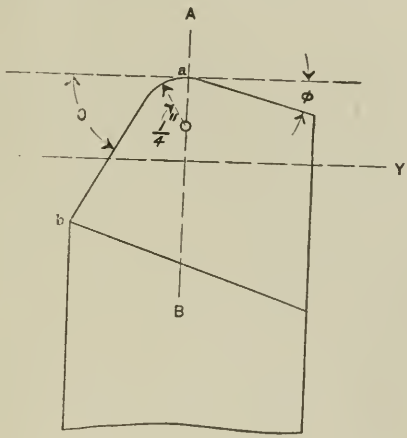


Fig. 86.—*Plan-view of Lathe Roughing Tool showing Variable Angle θ.*

terminating in a curve of $\frac{1}{4}$ inch radius. In this Table are also given the rake angles in the vertical planes represented by the lines AB and XY of the figure, the side rake being kept as nearly equal to 10° as possible, compatible with the cutting edge *ab* being horizontal.

The tests were made on the hard-steel test-bar, C, a constant average cutting speed of 26 feet per minute being maintained throughout each test with a depth of cut of $\frac{1}{4}$ inch and a feed of $\frac{1}{12}$ inch per revolution. The results of the tests are set forth in Table 15 (page 798).

These results are represented diagramatically in Fig. 87 (page 799), in which figure the net horse-power consumed is plotted against the angle θ (the general inclination of the cutting edge to the axis of

TABLE 12.

Forging Tests on Plain Carbon-Steel Tools.

Dimensions and Description of Tool.	Description of Test-Bar.	Starting Speed of Test.	Area of Cut. Depth × Feed.	Average Life of Tool.		Average Volume of Metal Removed.	Superiority (Based on Volume of Metal Removed).
		Feet per Min.		Min.	Sec.	Cub. In.	
$\frac{1}{2}$ in. sq. forged .	Hard Steel	10	$\frac{1}{8}$ in. × $\frac{1}{30}$ in.	7	40	5·17	
,, unforged .	(C)	,,	,,	7	47	5·31	2·7 per cent.
1 in. sq. forged .		,,	$\frac{1}{4}$ in. × $\frac{1}{30}$ in.	6	35	8·61	
,, unforged .		,,	,,	6	43	8·85	2·8 ,,
$\frac{1}{2}$ in. sq. forged .		20	$\frac{1}{8}$ in. × $\frac{1}{30}$ in.	17	8	24·4	
,, unforged .	Mild Steel	,,	,,	17	29	25·0	2·5 ,,
1 in. sq. forged .	(A)	,,	$\frac{1}{4}$ in. × $\frac{1}{30}$ in.	14	25	39·5	
,, unforged .		,,	,,	15	7	41·5	5·0 ,,
$\frac{1}{2}$ in. sq. forged .		20	$\frac{1}{8}$ in. × $\frac{1}{20}$ in.	11	21	21·7	
,, unforged .	Mild Steel	,,	,,	11	49	22·5	3·7 ,,
1 in. sq. forged .	(A)	,,	$\frac{1}{4}$ in. × $\frac{1}{20}$ in.	7	5	24·7	
,, unforged .		,,	,,	7	9	24·9	0·8 ,,

TABLE 13.

Forging Tests on Ordinary High-speed Steel Tools.

Dimensions and Description of Tool.	Description of Test-Bar.	Starting Speed.	Area of Cut. Depth × Feed.	Average Life of Tool.		Average Volume of Metal Removed.	Superiority (Based on Volume of Metal Removed).
		Feet per Min.		Min.	Sec.	Cub. In.	
$\frac{3}{4} \times \frac{1}{2}$ in. forged .		60	$\frac{1}{8}$ in. × $\frac{1}{30}$ in.	6	16	19·8	1·5 per cent.
,, unforged.	Hard Steel	,,	,,	6	1	19·5	
$1\frac{1}{4}$ in. sq. forged .	(C)	40	$\frac{3}{8}$ in. × $\frac{1}{20}$ in.	9	48	98·9	0 ,,
,, unforged.		,,	,,	9	48	98·9	
$\frac{3}{4} \times \frac{1}{2}$ in. forged .		100	$\frac{3}{16}$ in. × $\frac{1}{12}$ in.	9	13	182	
,, unforged.	Mild Steel	,,	,,	9	16	183	0·5 ,,
$1\frac{1}{4}$ in. sq. forged .	(A)	90	$\frac{3}{8}$ in. × $\frac{1}{12}$ in.	10	13	369	
,, unforged.		,,	,,	10	26	374	1·4 ,,

TABLE 14.

Angles of Lathe Turning Tools.

No. of Set.	Angle θ (Fig. 86).	Angle Φ (Fig. 86).	Angle in Plane AB (Front Rake).	Angle in Plane XY (Side Rake).	Clearance.
	Degs.	Degs.	Degs.	Degs.	Degs.
1	90	15	0	10	5
2	80	,,	1	,,	,,
3	65	,,	4	,,	,,
4	45	,,	10	,,	,,
5	30	,,	10	9	,,
6	15	,,	10	4	,,

TABLE 15.

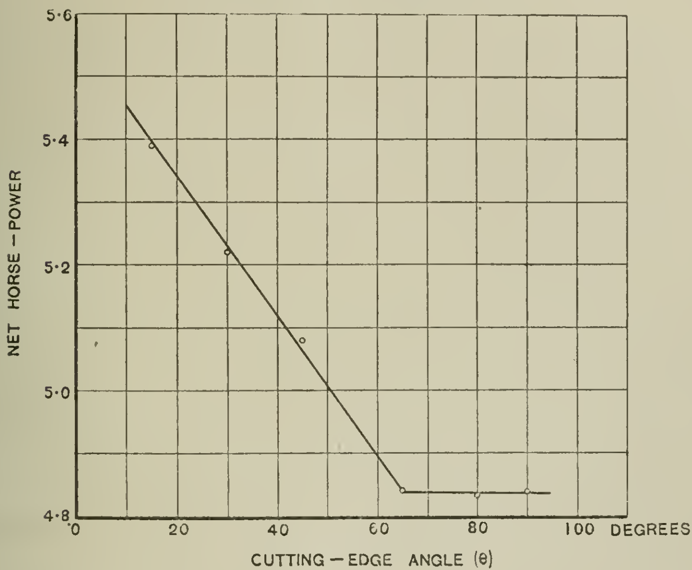
Net Power Consumption of Tools Described in Table 14.

No. of Set.	Net Horse-power consumed in Tests.
1	4·84
2	4·83
3	4·84
4	5·08
5	5·22
6	5·39

the test-bar or work-piece). This figure indicates that there is practically no variation in the net power consumption for all values of the mean axial angle of the cutting edge (θ) between 90° and 65° under the condition of nose-radius and depth of cut adopted in these tests. The explanation of this is that, under these

conditions, the length of the active part of the cutting edge is practically a constant quantity for all values of θ between 90° and 65° inclusive. This latter value of θ, however, appears to be a critical one for these conditions, since, with a reduction of the value of θ from this point, there is a general and comparatively constant increase in the net power consumption.

FIG. 87.—*Relation between Cutting-edge Angle* (θ) *and net Horse-power Consumed by Lathe Roughing Tool.*



Combining this result with the durability-test result, it would appear that an increase in the durability of a tool by reducing the mean axial cutting-edge angle below 65° can only be secured at the expense of the net power consumption. It is not, however, suggested that 65° is necessarily the critical value of this angle in every case, but that there is a critical value for each set of conditions of nose-radius and depth of cut which is peculiar to such conditions.

Some points of interest may be observed in the data arranged in Table 16, these data having reference to some of the

characteristics of the actual turnings removed by the above sets of tools.

TABLE 16.

Data Relating to Turnings from Hard-steel Test-Bar.

No. of Set of Tools.	Approximate Width of Turnings.	Approximate Mean Thickness of Turnings.	Approximate Mean Diameter of Coils of Turnings.
1	$\frac{3}{8}$ inch	$\frac{3}{16}$ inch	4 inches.
2	$\frac{3}{8}$,,	$\frac{3}{16}$,,	4 ,,
3	$\frac{3}{8}$,,	$\frac{3}{16}$,,	4 ,,
4	$\frac{7}{16}$,,	$\frac{9}{64}$,,	$3\frac{1}{2}$,,
5	$\frac{9}{16}$,,	$\frac{7}{64}$,,	$2\frac{3}{4}$,,
6	1 ,,	$\frac{1}{16}$,,	$\frac{5}{8}$,,

These data show that there is very little difference between the turnings removed by tools whose cutting edges are disposed at angles between 65° and 90° to the axis of the test-bar or work-piece, as would, of course, be expected from tools the active lengths of whose cutting edges are practically equal. On the other hand, there are great differences between the turnings removed by tools with cutting edges arranged at angles below 65° to the axis of the test-bar or work-piece. A comparison of Tables 15 and 16 will show that, whilst there is some connexion between the net power consumption and the general proportions of the turnings actually removed by turning tools working under conditions similar to the above, the variations of the former are not comparable with the latter.

9.—Influence of Cutting Speed on Net Energy per cubic inch of Metal removed by Lathe Roughing Tool.

Experiments to determine the influence, if any, of the cutting speed upon the net amount of energy consumed in the removal of a

cubic inch of metal from a steel test-bar or work-piece by a lathe roughing tool have also been conducted. These experiments were made with ordinary high-speed steel tools, $1\frac{1}{4}$ inch square in section, on both the afore-mentioned mild and hard-steel bars, A and C respectively. The standard shape of tool-nose of the original tests was adopted, the tools which were tested on the soft bar having a front rake of 11° and a side rake of 23°, whilst the corresponding angles ground on the tools which were tested on the hard bar were $4\frac{1}{2}$° and 10° respectively. In each case the clearance angles were 5°, and the cutting edges of all the tools were arranged in the horizontal plane which contained the common axis of the lathe centres.

Two sets of tests were made on each bar, each set with a different area of cut and embracing six or seven individual tests at each of a number of different speeds. In the case of the tests on the soft bar, it was found possible to work through a cutting-speed range from 10 to 120 feet per minute; whereas in the case of the tests on the hard bar, it was not found practicable to go beyond a cutting speed of about 60 feet per minute on account of the short life of the tools at speeds above this limit. The net power required in each test was determined by taking the difference between the total amount of power required with the tool actually cutting and that required with the tool out of action but moving with the slide-rest at the speed of the test feed. The volume of metal removed per hour was calculated from the data of the test in each case. The results of the tests are presented in Tables 17.

These results indicate that the specific net energy consumption is influenced only very slightly, if at all, by the magnitude of, or changes in, the cutting speed, and still less slightly by the magnitude of, or changes in, the area of cut. As a corollary, therefore, it follows that the specific forces which accompany cutting do not depend to any marked extent upon the cutting speed or the area of cut. In any case, the tendency to influence is opposite in character to the change in either cutting speed or area of cut. This conclusion is borne out by the test-results tabulated in the original Paper.

TABLE 17.

Energy per cubic inch of Metal removed by Turning Tool.

(*a*) Tests made on Mild-steel Bar with High-speed Tools.

Area of Cut.	Average Cutting Speed.	Cubic Inches removed per hour.	Net Power Consumed.	Cubic Inches per net h.p.-hour.		Net h.p.-hour per cubic inch.	
Inch.	Feet per Min.		h.p.				
$\frac{1}{4} \times \frac{1}{8}$	10·1	227	2·05	110·9		0·0090	
,,	21·0	472	4·09	115·4		0·0087	
,,	32·0	720	6·13	117·4		0·0085	
,,	43·5	990	8·48	116·8	118·0	0·0086	0·0085
,,	62·1	1,399	11·40	122·6		0·0082	
,,	79·0	1,778	14·74	120·6		0·0083	
,,	106·1	2,387	19·50	122·4		0·0082	
$\frac{1}{4} \times \frac{1}{12}$	10·1	152	1·35	112·2		0·0089	
,,	20·5	308	2·69	114·3		0·0088	
,,	33·5	503	4·35	115·6		0·0087	
,,	50·1	751	6·27	119·6	117·3	0·0084	0·0085
,,	69·5	1,043	8·74	119·3		0·0084	
,,	92·2	1,373	11·41	121·5		0·0082	
,,	118·5	1,778	15·00	118·5		0·0084	

(*b*) Tests made on Hard-steel Bar with High-speed Tools.

Area of Cut.	Average Cutting Speed.	Cubic Inches removed per hour.	Net Power Consumed.	Cubic Inches per net h.p.-hour.		Net h.p.-hour per cubic inch.	
Inch.	Feet per Min.		h.p.				
$\frac{1}{4} \times \frac{1}{12}$	6·8	102	1·23	82·5		0·0121	
,,	10·0	150	1·85	81·1		0·0123	
,,	18·1	271	3·35	81·2	82·0	0·0123	0·0122
,,	27·0	405	4·90	82·8		0·0120	
,,	38·5	578	7·06	81·7		0·0122	
,,	53·0	795	9·58	83·0		0·0120	
$\frac{1}{4} \times \frac{1}{20}$	7·1	64	0·78	81·9		0·0122	
,,	10·7	96	1·18	81·6		0·0122	
,,	18·2	164	2·02	81·1		0·0123	
,,	31·5	284	3·52	80·5	81·5	0·0124	0·0122
,,	40·5	365	4·30	80·7		0·0124	
,,	48·5	441	5·38	82·0		0·0122	
,,	58·0	522	6·29	83·0		0·0120	

10.—Cooling and Lubrication Tests.

In all the tests, except the finishing tests, which have so far been described, no cooling or lubricating medium of any kind was employed, each tool being tested "dry." Tests have, however been made with the object of determining the quantitative effect of a stream of liquid having cooling and lubricating properties on the cutting qualities of a lathe rough-turning tool.

These tests were made with twelve $1\frac{1}{4}$ inch square ordinary high-speed steel tools, all ground alike to the standard shape with a cutting-edge radius of $\frac{5}{32}$ inch, and all hardened alike. The tool angles were as follows:—

Top rake—front = 11°. Front clearance = 5°.
" " —side = 23°. Side " = 5°.

The test-bar selected for these experiments was the mild-steel bar, A, already described. On this bar the cut was $\frac{1}{4}$ inch deep, with a feed of $\frac{1}{12}$ inch per revolution of the bar. The test applied was the ordinary speed-increment test, the starting speed being 50 feet per minute, and the speed-increment 1 foot per minute per minute.

Two sets of experiments were made. In the first set, a soluble-oil compound diluted with water in the ratio of 3 to 1 was used as the lubricant-coolant; in the second set, compressed air was used as the coolant, both with and without the diluted soluble-oil compound.

In the first set of tests a nozzle $\frac{5}{16}$ inch in diameter was used to direct the stream of coolant on to the turning or chip at the point at which it left the bar, as shown at A in Fig. 88 (page 804). This is, generally, the direction of a stream of coolant which is the most easily attainable. The water was put into motion by means of an electrically-driven geared pump, the speed of which was varied to give different stream flows or velocities. At each stream flow or velocity, which was actually measured, three separate tests were made, the average results of which are given in Table 18. From this Table it will be observed that the greatest flow used in the tests was equal to about 1 gallon of water being projected on the turning per minute.

The results in Table 18 indicate that the gain to be derived from the use of a stream of coolant on a lathe turning tool working on steel is not a constant quantity, but rises simultaneously with the flow of the coolant when the velocity of discharge of the latter bears a constant ratio to the rate of discharge. The results of other tests, however, appear to show that there is a limiting rate af flow of coolant in every case, and that beyond this rate of flow no increase of gain in the cutting speed or capabilities of the tool

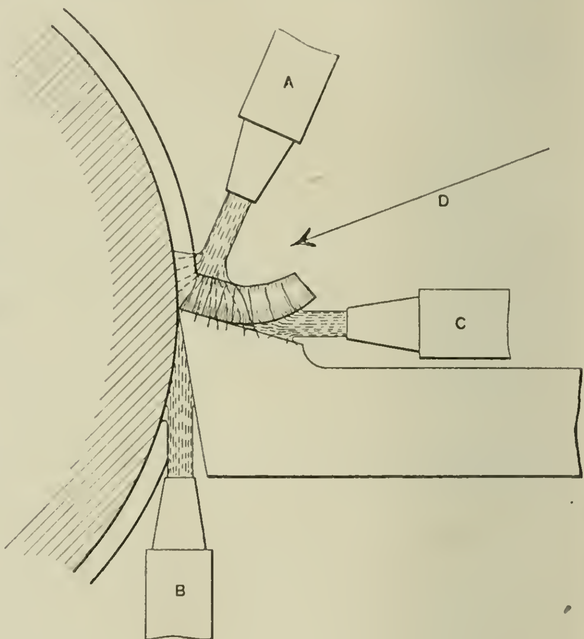


FIG. 88.
Diagram showing Direction of Flow of Cooling Media on Lathe Turning Tool and Turning.

can be secured, but that rather there is an actual falling-off of the gain secured at the limiting rate of flow. In the above case, the limiting rate is probably in the neighbourhood of the rate corresponding to the maximum flow used.

The results of other tests demonstrate that, if the same flow is used in conjunction with a smaller area of cut, or a stream of proportionately larger section with the same velocity is used in

TABLE 18.

Effect of Coolant on Cutting Qualities of High-speed Lathe Tools.

Direction of Flow of Coolant: A (Fig. 88) on Turning.

Starting Speed = 50 feet per min. Area of Cut = $\frac{1}{4}$ in. deep × $\frac{1}{12}$ in. feed.

Flow of Coolant.		Average Life of Tool.		Average Breakdown Speed.	Average Volume of Metal Removed.	Improvement in Cutting Qualities of Tools.
Cub. Ft. per Min.	Gallons per Hour.	Min.	Sec.	Feet per Min.	Cub. In.	Per Cent.
0	0	13	41	63·3	194·0	0
0·0245	9·17	16	19	66·0	236·7	22
0·0648	24·24	17	7	66·3	249·6	29
0·1053	39·40	17	45	67·3	260·5	34
0·1532	57·32	18	8	68·0	267·5	38

Average percentage improvement in the cutting qualities of the tools due to the influence of the coolant at various flows = 31 per cent.

conjunction with the same area of cut, the improvement in the cutting capabilities of the tool is, within limits, increased.

In Table 19 (page 806) are given the results of tests made with a view to the determination of the effect of a reduction in the area of cut upon the improvement in the cutting power of a high-speed lathe tool registered as the result of the use of a stream of coolant. In these tests, the comparative speed-increment test was applied as above, the starting speed being 20 feet per minute, and the increment of speed 1 foot per minute applied every minute. The tools experimented with were made from $\frac{3}{4}$ inch by $\frac{1}{2}$ inch bars, and ground to the standard shape with angles suitable for use on the hard-steel bar, C, on which the tests were made. The area of cut adopted was $\frac{1}{8}$ inch deep by $\frac{1}{12}$ inch traverse, this being found to give a tool life ranging from 15 minutes to 23 minutes. This

area of cut is just one-half of that adopted in the previous tests, the reduction being obtained by halving the depth of cut.

TABLE 19.

Effect of Area of Cut on improvement in Cutting Power High-speed Lathe Tools due to use of Coolant.

Direction of Flow of Coolant: A (Fig. 88) on Turning.

Starting Speed = 20 feet per min. Area of Cut = $\frac{1}{8}$ in. deep × $\frac{1}{32}$ in. feed.

Flow of Coolant.		Average Life of Tool.		Average Breakdown Speed.	Average Volume of Metal Removed.	Improvement in Cutting Qualities of Tools.
Cub. Ft. per Min.	Gallons per Hour.	Min.	Sec.	Feet per Min.	Cub. In.	Per Cent.
0	0	15	3	34·5	51·3	0
0·0245	9·17	18	45	38·5	69·1	35
0·0648	24·24	22	10	42·0	85·7	67
0·1053	39·40	22	52	42·3	89·1	74
0.1532	57·32	22	11	41·3	85·5	67

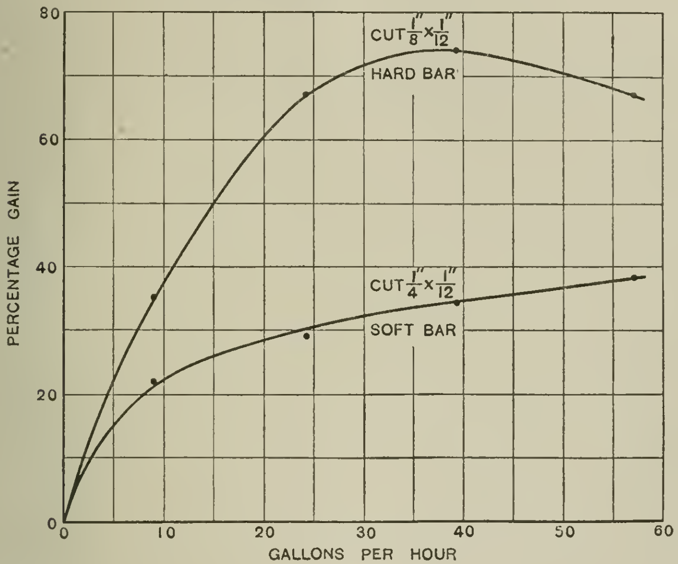
Average percentage improvement in the cutting qualities of the tools due to the influence of the coolant at various flows = 61 per cent.

A comparison of this and the immediately preceding Table, as well as the curves given in Fig. 89 and based upon these Tables, will show that the percentage improvement in the cutting power of the tools is greater for each flow with the smaller area of cut, the ratio of the average percentage improvements in cutting power for the two areas of cut being practically 2 to 1 in favour of the smaller area of cut. This ratio, it is to be noted, is approximately equal to the reciprocal ratio of the active lengths of cutting edge in the two cases, and that it is quite probable that a reduction in the feed instead of a reduction in the depth of cut would not have resulted in such a large increase in the gain of cutting power.

It is, further, quite reasonable to assume that there is a limiting area of cut for each section of stream, and that no increase in the gain of cutting power can be registered as the result of any further reduction in the area of cut below this value.

The phenomenon of the limiting flow of coolant under conditions which are otherwise constant is observable in connexion with Table 19, and the upper curve in Fig. 89. The explanation of

Fig. 89.—*Lathe-tool Cooling Tests.*



this phenomenon is probably to be found in the fact that at practically all stream velocities there is a perceptible amount of splashing, and that as the velocity is increased the amount of splashing is also increased, not necessarily in direct proportion to the velocity-increase, but, as is more probable, to the square of the velocity-increase. Beyond a certain velocity (the velocity corresponding to the limiting or critical rate of flow for the particular conditions obtaining in any case) the loss due to the increased splashing is greater than the gain due to the increased

Fig. 90.—*Lathe-tool Cooling Tests.*

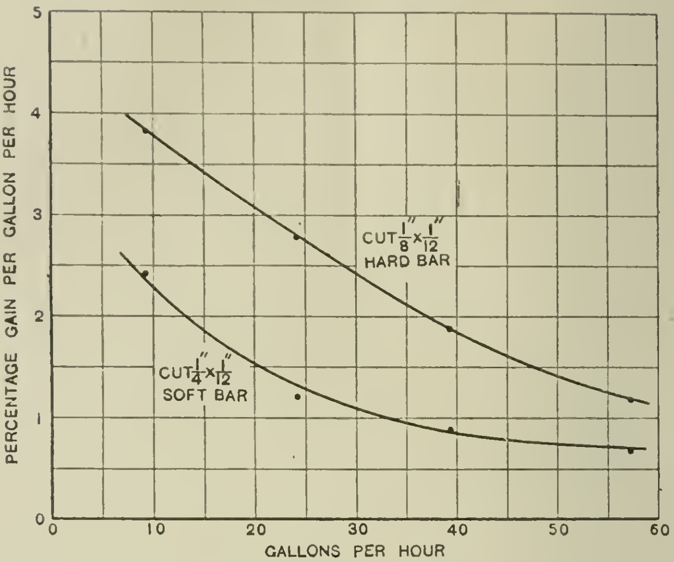
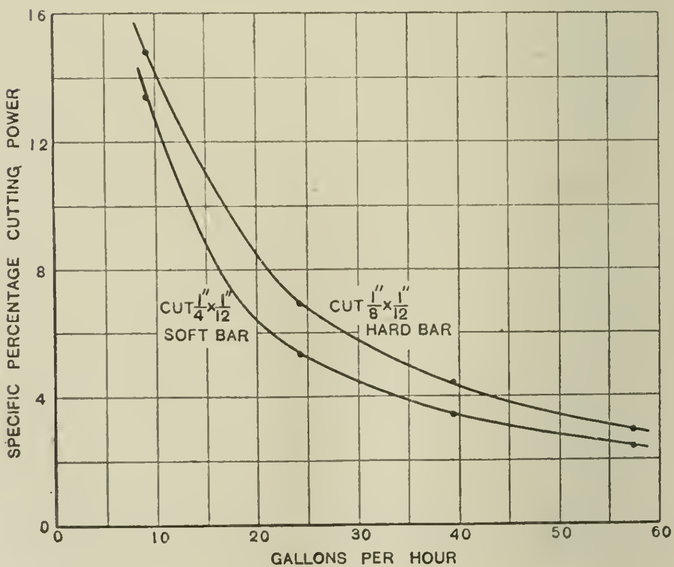


Fig. 91.—*Lathe-tool Cooling Tests.*



flow, and the increase in the velocity of the useful part of the stream, with the result that the net heat-extracting power of the stream is actually reduced, this producing a reduction in the cutting power and durability of the tool.

Regarding the question of the magnitude of the critical or limiting velocity or rate of flow of the stream or coolant, it should be observed that this does not appear to be a constant quantity for all cases, but that it probably depends upon the section of the stream and its relation to the area of cut. This will be seen from a comparison of Tables 18 and 19, and of the curves given in Fig. 89. In one case, the limiting rate of flow has, apparently, not been quite reached ; in the other, its magnitude is clearly indicated at 0·1053 cubic foot per minute (39·40 gallons per hour), corresponding in this particular case to a stream velocity of 3·30 feet per second.

An interesting deduction from Tables 18 and 19 is shown in Table 20 (page 810). It is in regard to the relations between the rate of flow of the coolant, and (1) the specific percentage improvement in cutting power (that is, the percentage improvement in cutting power per gallon of coolant per hour), and (2) the specific percentage cutting power (that is, the percentage cutting power per gallon of coolant per hour, with the "dry" or "uncooled and unlubricated" cutting power taken as the standard and represented as 100).

This Table shows, as do the curves given in Figs. 90 and 91, that each of these two specific percentages falls as the rate and velocity of flow of the coolant are increased. It will also be observed that the specific percentage cutting powers for each flow of coolant with the two areas of cut on different test-bars are not very different, this suggesting that the specific percentage cutting power of a tool when working with a coolant does not depend to any material extent upon the relation between the section of the stream of coolant and the area of cut.

A number of tests were made with the object of determining the effect of a variation in the velocity of the flow whilst the rate of flow is kept constant. A variation in the velocity under such conditions is, of course, only possible by varying the cross-sectional area of the stream. This was actually done by substituting a nozzle

TABLE 20.

Specific Percentage Improvement in Cutting Power due to use of Coolant on Turning Tools.

Deduced from Data given in Tables 18 and 19.

Coolant Data.		Gain per cent per gallon per hour.		Cutting Power per cent. per gallon per hour.	
Flow in Gallons per hour.	Velocity of Stream in feet per second.	Cut, $\frac{1}{4} \times \frac{1}{12}$ inch on Mild Steel.	Cut, $\frac{1}{8} \times \frac{1}{12}$ inch on Hard Steel.	Cut, $\frac{1}{4} \times \frac{1}{12}$ inch on Mild Steel.	Cut, $\frac{1}{8} \times \frac{1}{12}$ inch on Hard Steel.
0	0	0	0	—	—
9·17	0·77	2·41	3·82	13·4	14·8
24·24	2·03	1·20	2·77	5·3	6·9
39·40	3·30	0·87	1·88	3·4	4·4
57·32	4·80	0·66	1·17	2·4	2·9

$\frac{5}{8}$ inch in diameter for the $\frac{5}{16}$-inch nozzle as used in the first tests. Other conditions, however, were identical with those of the tests of Table 18, a rate of flow of 0·1532 cubic foot per minute (57·32 gallons per hour) being adopted for the purposes of comparison. With this rate of flow, an improvement in cutting power of 37·5 per cent was registered against the 38 per cent of the Table obtained under identical conditions apart from the velocity of flow and the cross-section of the stream. This would seem to show that there is no material gain in cutting power to be secured by the use of a heavy stream at a low velocity as against a lighter stream at a higher velocity, other things being equal, provided that absurdly heavy or light stream-flows are not employed. On the other hand, there is less splashing and throwing of water when the stream is large and the velocity low than when the stream is fine and the velocity high.

The results of these tests are also useful for the purpose of showing the effect of an increase of stream-flow with a constant

velocity of flow. Thus, taking the rate of flow through the $\frac{5}{8}$-inch nozzle at 0·1532 cubic feet per minute (57·32 gallons per hour), we find that the rate of flow through the $\frac{5}{16}$-inch nozzle at the same velocity would be $\frac{0 \cdot 1532}{4}$ or 0·0383 cubic feet per minute (14·33 gallons per hour); and from the lower curve of Fig. 89 (page 807) we find that the percentage improvement in cutting power which would be obtained, under the conditions of the tests of Table 18 is 24·5 per cent, which compares with the 37·5 per cent obtained with the four-fold rate of flow. That is to say, by increasing the rate of flow and cross-section of the stream each by 300 per cent, the gain in actual cutting power is increased by only 50 per cent.

Further experiments have been made to determine whether any one direction of the stream of coolant with respect to the cutting edge of the tool is superior to all the others. For this purpose, the conditions of the first tests were repeated with the one exception of the direction of the flow. This latter was changed first to that shown at B in Fig. 88, and then to that shown at C. In the first of these two cases, the nozzle was pointed upwards between the flank of the tool-nose and the test-bar so that the stream of coolant was projected into the angle formed between them. In the second case, the position of the nozzle was such that the stream of coolant was projected between the turning formed from the test-bar and the lip surface of the tool-nose with the object of forcing it as near to the cutting edge as possible.

Tests with two different flows of coolant with direction B were made, the results of these being given in Table 21 (page 812).

If comparison be made between this Table and Table 18, it will be seen that with this direction of flow there is a gain of 49 per cent. as against one of 29 per cent for the more usual direction of flow, and again one of 70 per cent as against one of 34 per cent. These results indicate that this direction of flow is the more efficient of the two; but this is only the case provided that the velocity of flow of the coolant is such that the stream reaches the cutting edge quite readily. When this condition is not satisfied, the gain in cutting power is only very slight.

TABLE 21.

Effect of Direction of Flow on Gain secured by use of Coolant.

Direction of Flow of Coolant: B (Fig. 88) between Tool and Test Bar.
Starting Speed = 50 feet per min. Area of Cut = $\frac{1}{4}$ in. deep × $\frac{1}{12}$ in. feed.

Flow of Coolant.		Average Life of Tool.		Average Breakdown Speed.	Average Volume of Metal Removed.	Improvement in Cutting Qualities of Tools.
Cu. Ft. per Min.	Gallons per Hour.	Min.	Sec.	Feet per Min.	Cub. In.	Per Cent.
0·0648	24·24	19	28	69·0	289·7	49
0·1053	39·40	21	45	71·3	329·7	70

Tests were made with only one rate of flow of coolant with the direction C; the results of these are given in Table 22.

TABLE 22.

Effect of Direction of Flow on Gain secured by use of Coolant.

Direction of Flow of Coolant: C (Fig. 88) between Tool and Turning.
Starting Speed = 50 feet per min. Area of Cut = $\frac{1}{4}$ in. deep × $\frac{1}{12}$ in. feed.

Flow of Coolant.		Average Life of Tools.		Average Breakdown Speed.	Average Volume of Metal Removed.	Improvement in Cutting Qualities of Tools.
Cub. Ft. per Min.	Gallons per Hour.	Min.	Sec.	Feet per Min.	Cub. In.	Per Cent.
0.1532	57·32	17	31	67·0	256·4	32

A comparison between this Table and Table 18 will show that the use of a stream of coolant with this direction of flow produces results which are inferior to those obtained with the ordinary

direction of flow on the turning, this percentage gain in cutting power of 32 per cent being comparable with the 38 per cent gain of Table 18.

Experiments have also been made with a combination of two streams of coolant, the two flows A and B of Fig. 88 forming the combination. In the actual tests the rate of flow in the direction A was 0·1053 cubic foot per minute (39·40 gallons per hour), whilst that in the other direction was 0·0648 cubic foot per minute (24·24 gallons per hour), making a total rate of flow of 0·1701 cubic foot per minute (63·64 gallons per hour). The above test conditions were the same as those which obtained in the first set of coolant tests. The average results of the tests are given in Table 23, from which it will be seen that the cutting qualities of the tools under these conditions were the greatest recorded. Furthermore, it will be observed that the improvement in cutting power due to this combination of flows is practically equal to the sum of the individual improvements which are registered when the two flows are made use of separately. Thus, the sum of these two improvements (as taken from the Tables) equals (34+49), that is, 83 per cent, a result which compares with the 87 per cent gain which is registered in this case.

TABLE 23.

Effect of Compound Flow of Coolant on Cutting Power of Lathe Tool.

Directions of Flow: A and B (Fig. 88).
Starting Speed = 50 feet per min. Area of Cut = $\frac{1}{4}$ in. deep × $\frac{1}{12}$ in. feed.

Total Flow of Coolant.		Average Life of Tools.		Average Breakdown Speed.	Average Volume of Metal Removed.	Improvement in Cutting Qualities of Tools.
Cub. Ft. per Min.	Gallons per Hour.	Min.	Sec.	Feet per Min.	Cub. In.	Per Cent.
0·1701	63·64	23	10	73·0	362·7	87

As an addendum to the above, experiments were made with compressed-air as the cooling medium. In these tests the air was compressed to a gauge pressure of 50 lb. per square inch, and then conducted from the receiver through a $\frac{1}{2}$-inch pipe 45 yards long, this pipe terminating in a length of rubber-and-canvas hose-pipe, which carried at its outer end a steel nozzle of $\frac{3}{8}$-inch bore. The air, which was on the moist side, was projected directly on the turning and nose of the tool at the place where the turning left the bar, as shown by the arrow D in Fig. 88. The test conditions, other than in regard to the method of cooling, were precisely the same as those of all the other coolant tests on the mild-steel bar A. That is, the speed-increment test was adopted with an initial cutting speed of 50 feet per minute and minute speed-increments of 1 foot per minute. The results of these tests are given in Table 24, from which it will be seen that this method of cooling the turning and the tool is not apparently as effective as the method which involves the use of water as the cooling agent. Its chief virtue would appear to be that the use of compressed air is considerably cleaner than the use of water, whether the latter is used with soluble oil or soda in solution or not. On the other hand, it is objectionable on account of the noise which is caused by the emission of the air in the volume and at the velocity necessary to secure any appreciable cooling effect.

TABLE 24.

Results of Tests with Compressed Air as Coolant.

Direction of Flow: D (Fig. 88) on Turning and Nose of Tool.
Starting Speed = 50 feet per min. Area of Cut = $\frac{1}{4}$ in. deep × $\frac{1}{12}$ in. feed.

Average Life of Tools.	Average Breakdown Speed.	Average Volume of Metal Removed.	Improvement in Cutting Qualities of Tools.
Min. Sec.	Feet per Min.	Cub. In.	Per Cent.
16 17	66.0	236·1	22

Further tests were made with this method of cooling the tool and turning, but with this method in combination with the water-cooling method. The rate of flow of water which was used was 0·1053 cubic foot per minute (39·40 gallons per hour), whilst the direction of the flow was upwards (*vide* Fig. 88 at B). The results of these tests, whose other conditions were as above, are given in Table 25.

TABLE 25.

Combination of Water and Air as Coolants for Turning Tool.

Directions of Streams: B (Fig. 88) for Water, and D (Fig. 88) for Air.
Starting Speed = 50 feet per min. Area of Cut = $\frac{1}{4}$ in. deep × $\frac{1}{12}$ in. feed.

Flow of Water.		Average Life of Tools.		Average Breakdown Speed.	Average Volume of Metal Removed.	Improvement in Cutting Qualities of Tools.
Cub. Ft. per Min.	Gallons per Hour.	Min.	Sec.	Feet per Min.	Cub. In.	Per Cent.
0·1053	39·40	22	55	72·7	351·5	81

It will be noticed that this percentage gain is less than the sum of the percentage improvements in the cutting power due to the individual streams, which sum is equal to (70 + 22) or 92 per cent. This may be partly accounted for by the slight spreading of the stream of water which is caused by the rapidity of the movement of the air as it impinges on the turning and tool. It will be further noticed that this combination is not quite as effective as the water—water combination of directions A and B, the comparison being a gain of 81 per cent against one of 87 per cent respectively.

Regarding the average effect of a stream of water as a cooling agent on the cutting power of ordinary high-speed lathe turning tools, the above results give an improvement or gain of 50 per cent which compares with the 40 per cent increase in cutting speed attributable to the same cause as given by the late Mr. F. W. Taylor.*

* Proceedings, A.S.M.E., Vol. 28, No. 3, page 140.

11.—Influence of the use of a Coolant on the Net Power Consumption with High-Speed Lathe Tools.

It has been stated that the use of a cooling medium in lathe roughing operations with high-speed tools results in an appreciable reduction in the power consumed, other things, of course, being equal, a reduction of about 40 per cent being reported in one case. To test this point a number of tests have been made with high-speed roughing tools of various sections working on steel bars of several qualities, but no such large reduction has been observed, and, as a matter of fact, no appreciable reduction at all has been registered. The coolant (which was the above water and soluble oil mixture) was projected on the tool and turning in each of the directions A and B, Fig. 88, but in every case both the net and gross power-consumptions were respectively the same as when the tool was worked dry. This seems to point, in the case of external single-edged cutting tools, to the fact that the coolant does not act as a lubricant between the chip or turning and the lip of the tool, a result which appears to be quite reasonable in view of the enormous pressure which exists between these two elements.

The only functions of the cooling medium in roughing-out operations appear, therefore, to be that of cooling the turning and retarding the rate of heating of the nose of the tool. This latter function has probably an influence upon the rate of grooving of the lip surface of the tool, and this in turn appears largely to be the determining factor in connexion with the durability and cutting power of a lathe high-speed roughing tool.

12.—Condition of Cutting Edges of High-Speed Turning Tools with respect to Efficiency of Cutting.

It has been suggested that a reasonable deduction from the results and observations of high-speed turning tool tests is that extreme sharpness of the cutting edge is not an essential condition of the efficient removal of metal from a steel test-bar or work-piece. To test the validity of this contention, comparative tests have been made with sharp-edged tools and tools with artificially blunted

edges. In these tests, apart from this one difference, all the tools were similar, and each tool was tested in precisely the same way. At a cutting speed of 26 feet per minute on the mild-steel test bar, A, the blunted tools tore rather than cut the metal from the bar, the cutting action being generally very unsatisfactory. Furthermore, the thickness of the chips removed was much less than that of the chips removed by the sharp tools with the same feed and depth of cut. At a cutting speed of 75 feet per minute, the blunt tools cut much better than at the lower speed, but even at this speed their cutting action was not at all comparable with that of the sharp tools on the same bar. Furthermore, the resistance to cutting at the edges of the blunt tools was so great that these tools were progressively pushed away from the test-bar.

The deduction to be drawn from these results is that a sharp cutting edge is a *sine qua non* in connexion with the efficient working of a high-speed roughing tool on plain carbon-steel, and that as the bluntness of the edge is increased the efficiency of the cutting action of the tool is reduced. A further deduction is that the effect of the bluntness of the cutting edge of a high-speed tool working on a plain carbon-steel work-piece is less pronounced at high cutting speeds than at low ones.

In connexion with the machining of the more modern alloy steels with heavy cuts at low speeds, it is often found that there is a building-up effect on the cutting edge of a high-speed steel tool which is not very different from that which occurs with plain carbon-steel tools working with lighter cuts on plain carbon-steel work-pieces. A tool so built-up will generally continue to cut although the real cutting edge of the tool may be comparatively blunt, but a point is always reached when the real cutting edge of the tool is too blunt to sustain the built-up edge, with the consequence that efficient cutting ceases. Before this point is reached, however, if the tool is withdrawn from the work-piece, it is generally found that, if the cutting edge shows signs of a real blunting effect jointly on the flank and lip surfaces, the cutting action of the tool cannot be restarted to produce satisfactory results with the cutting edge in that condition. This is particularly the

case if the machined surface against which the unground tool is fed is superhardened and polished, even only partially as sometimes it is when only a portion of the active part of the cutting edge has reached the limiting degree of bluntness.

On the other hand, a high-speed steel tool with a very sharp cutting edge, as distinct from a keen tool angle, when working on a hard variety of alloy steel, such as, for example, a high nickel-chromium steel, in the annealed or normalized state, the turnings show signs of the occurrence of complete fracture in shear, and they leave the bar in the form of comparatively short chips, fairly heavy vibrations being, as a result, set up in the bar and the machine. This effect, however, is toned down as the cutting proceeds and the extreme sharpness of the cutting edge of the tool is worn off.

This should not be taken as an argument against the necessity of a sharp cutting edge on the tool, since cutting in such a case will not proceed if the cutting edge at the commencement of the cut is blunt even to a slight extent.

CONCLUSIONS.

1.—That there is no practical cutting speed below which it is impossible to obtain a satisfactory surface on plain-carbon steels by means of ordinary lathe finishing tools, whether these be made of plain-carbon tool steel, ordinary (non-vanadium) high-speed steel, or superior (vanadium) high-speed steel. There is, however, a maximum limiting speed at above which a satisfactory finish cannot be obtained on account of the tendency of the tool to pluck at and tear the surface, this tendency being related to the phenomenon of building-up on the cutting edge of the tool. For the finishing of mild steel, this limit is not very different for each of the above three varieties of tool steel and is within the range of 48 to 58 feet per minute. For the finishing of hard steel, this limit does depend somewhat on the variety of tool steel which is employed and is within the ranges of 23 to 28, 17 to 21, and 28 to 34 feet per minute for the three varieties of tool steel respectively.

2.—The durability or life of a lathe finishing tool, whether of plain-carbon or high-speed steel, is for all cutting speeds below the limiting speed some function of the reciprocal of the cutting speed; in other words, an increase in the cutting speed below the limiting value is always accompanied by a decrease in the life or durability of the tool.

3.—The most suitable angle of side rake (that is, the angle of side rake associated with maximum durability and cutting power) for a high-speed lathe roughing tool working on steel depends upon the physical properties of the steel. For mild-steel turning, it lies between 20° and 25°, whilst for hard-steel turning, it is of the order of 10°; and if these angles are either increased or reduced there is always a depreciation of cutting power.

4.—The colour of the turnings formed by a high-speed lathe roughing tool when working on steel is not necessarily a true index of the condition of maximum cutting efficiency. Thus, in the case of hard-steel turning, the turning colour which is associated with maximum cutting efficiency is a pale blue, whilst a mild-steel turning which is removed under the conditions of maximum efficiency is practically uncoloured, apart, of course, from the natural grey colour of the steel.

5.—The net power consumption of a high-speed roughing tool is dependent, other conditions being constant, upon the amount of toprake on the tool, the relation between these two quantities being reciprocal in character, so that, within the limits of ordinary practice, a reduction in the top-rake angles of a tool is always accompanied by an increase in the net amount of power consumed. The law connecting the variations of the two quantities appears to be of the nature of a straight-line law for all qualities of steel machined. There are, therefore, no critical values of the rake angles in regard to power consumption as there are in regard to durability and cutting power.

6.—The cutting power of a high-speed lathe tool is influenced by both the cross-sectional area of the shank of the tool and the nose-radius, but the influence of the latter factor very largely predominates in all cases. Thus, with a number of different

sections of tool steel, an increase of the nose-radius of 100 per cent produced an average increase in the cutting power of 45 per cent; whereas an increase of the cross-section of the shank of the tool of 500 per cent with a constant nose-radius produced an average increase in the cutting power of only 8·5 per cent.

7.—The effect of raising a roughing tool so that its cutting edge is slightly above the horizontal plane passing through the lathe centres is, generally, to increase the cutting power of the tool slightly and to reduce its net power consumption slightly, when compared with its normal position, that is, with its cutting edge at the same height as the lathe centre axis.

8.—Forging the nose of a lathe cutting tool does not materially affect its cutting power and durability, there being practically nothing to choose between a completely ground tool and a forged and ground tool, otherwise identical.

9.—The general direction and the active length of the cutting edge of a high-speed tool have a slight influence upon the net power consumption of the tool, the influence being such that, with any given depth of cut, if the active length of the cutting edge is increased by an alteration of the general direction of the edge, the net power consumed is increased under conditions of working otherwise identical.

10.—There is no marked difference in the net amounts of energy required per cubic inch of material removed from mild-steel and hard-steel bars at high and low cutting speeds.

11.—The increase in the cutting power of a high-speed roughing tool resulting from the use of a given stream of water as a cooling agent is greater with small cuts than with heavier ones, indicating that, with heavier cuts, heavier flows of coolant should be used. The velocity of flow of a stream of coolant does not very materially affect the improvement in the cutting power of a tool due to the use of the coolant, provided that the velocity is not such as to cause excessive splashing of the coolant.

12.—The cutting efficiency of a high-speed roughing tool depends very largely upon the condition of the cutting edge of the tool, and though a tool with its cutting edge blunted in the cutting process

may continue to cut, it cannot be used in that condition for the purpose of starting a new cut.

In closing, the Author wishes to acknowledge his indebtedness to Professor W. Ripper, C.H., D.Eng., D.Sc., for the interest which he has taken in this work and for the facilities which have been placed at the disposal of the Author to enable the work to be done.

The Paper is illustrated by 24 Figs. in the letterpress, and is accompanied by 2 Appendixes.

APPENDIX VII.

Chemical Compositions of Test-Bars.

Letter of Identification.	Carbon.	Silicon.	Manganese.	Sulphur.	Phosphorus.	Nature of Steel.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	
A	0·29	0·100	0·42	0·037	0·028	Mild Steel.
B	0·39	0·075	0·50	0·030	0·038	Medium Steel.
C	0·60	0·249	0·83	0·053	0·030	Hard Steel.
W	0·23	0·027	0·45	0·025	0·025	Mild Steel.
Z	0·82	0·030	0·36	0·032	0·040	Very Hard Steel.

APPENDIX VIII.

Physical Properties of Test-Bars.

Letter of Identification.	Breaking Load.	Elongation.	Compressive Load.	Brinell Hardness Numeral.	Shore Scleroscope Value.
	Tons per Sq. Inch.	Per cent.	Tons per Sq. Inch.		
A	27·2	28·4	81·2	131	22
B	33·5	21·7	90·0	146	24
C	50·5	12·0	126·4	223	33
W	24·8	28·8	74·8	126	21
Z	51·2	9·3	128·0	241	40

Discussion in London, 19th December 1919.

The Chairman (Captain H. Riall Sankey, C.B., R.E., *Vice-President*) said that the Author in the short time at his disposal had given a very fair résumé of his Paper, which was a most interesting one; the information contained in it was of considerable value and should be of great use to mechanical engineers especially. He thought an excellent discussion ought to ensue, but before it started he asked the members to pass a hearty vote of thanks to the Author for his Paper.

The resolution of thanks was carried by acclamation.

Dr. William Ripper, C.H., in opening the discussion, said he remembered particularly well the reading of the first part of the Paper in November 1913, when Sir Frederick Donaldson, the then President, was in the Chair. On that occasion the late Professor Robert H. Smith was present and made a most interesting contribution to the discussion. The Chairman had referred at the opening of the Meeting to the sad death of their old friend Mr. J. Hartley Wicksteed. Speaking as one of the Old Brigade, the ranks of which were getting thinner every day, he most sincerely wished to join in the Chairman's expression of deep regret at the loss to the Institution of so valuable a Member. Those who knew Mr. Wicksteed were well aware of how sound and strong a man he was. He was not only a great engineer, but a great man—a man of sterling qualities, the like of whom the Institution could very badly spare. He desired to take the present opportunity of adding his word of sympathy to those which the Chairman had uttered at the sad loss they had sustained.

When the first Part of the Paper was submitted to the Institution, it was presented jointly by Mr. Burley and himself. The Author very loyally, very industriously, and very ably helped him in the preparation of that Paper. When the War broke out he (Dr. Ripper) was taken off from his ordinary work, which he had not been able to touch for about four years, so that all he had

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had to do with the present Paper was to afford the Author all the facilities that he could, with an occasional word of help and encouragement. He had done nothing more in connexion with it. But he had followed what the Author had been doing and he had been very much interested in the results he had obtained. He would like to say that when the Paper was begun, the Authors never had any such ambitious intention as to lay down dogmatically the laws of cutting tools. What made them start the work was a statement to the effect that their old and well-established ideas about the behaviour of cutting tools were somehow not thoroughly reliable, that they were at times subject to variations, freaks and exceptions, which, speaking for himself, seemed rather staggering. He therefore felt it was important to do something to try to confirm their general ideas of the behaviour of cutting tools, or to discover what were the facts. For that purpose they cut down every possible variable. They had standard tool shapes, no lubrication, and standard angles of rake. Obviously those conditions were by no means the sort of conditions upon which one had any right to base general laws of the behaviour of cutting tools. All one could do at that time was to try to establish roughly and generally those principles which obtained in that kind of work. But unfortunately, in the discussion that took place on the previous occasion, the Authors' principal point, namely, the endeavour to establish the conditions of cutting of a tool in a lathe, was lost sight of, and in particular the speeds which they deduced from the experiments that were made were pointed out as being low and not comparable with workshop practice. He thought the Authors themselves were probably to blame for that, because they did not separate properly and sufficiently those two points, namely, the laying down of general principles requiring the avoidance of a number of variables, and not any attempt on their part as a primary object to establish laws common to all and every type of tool performance in a workshop.

It had been of very great interest to him to follow the growth of the formulæ that were originally deduced from the curves of performance in the early experiments. During the work which

Mr. Burley had recorded in this Paper, conditions had been included which the Authors omitted in the original Paper, namely, rake-angle, nose-radius, lubrication, and so on. He had shown, as they would all expect, continued improvement in efficiency when the most suitable rake-angle was substituted for a constant angle, and when lubrication was included. The result was that the formulæ of efficiency, taking all those variables into consideration, were very different from the formulæ originally laid down, which did not represent, and were not intended to represent, general workshop practice under the best conditions. He had had those formulæ collected, starting with the first one and then showing the effect of the various variables that had now been introduced. He also suggested to the Author that, instead of leaving the Paper with the formulæ only, it would be of very great assistance to everybody if he would get out from the formulæ the necessary Tables of speeds for all ordinary practical work. The addition of that Table or Tables would, he was sure, greatly add to the practical value of the Paper. [*See* pages 904–7.]

The Paper dealt with only a very small part of the whole question, and was not intended to be considered in any sense exhaustive. It merely dealt with the turning of steel. A multitude of other problems involved in lathe work, awaited attention, including the turning of cast-iron, the new metals and the new alloy metals, and a very great amount of work lay before those who had the patience and the opportunity to carry out such work. He only desired to say, in conclusion, that, if the University of Sheffield could help the mechanical engineering industry by continuing to devote time and effort to that kind of work, he was sure it was its desire to do so, and the University would very much appreciate any encouragement the Institution found it possible to give in furtherance of such work.

Mr. P. V. Vernon, O.B.E., said that, before dealing with the subject matter of the Paper, he desired to congratulate the Author upon the arrangement of the Paper. He found it most convenient to have the preamble of the Paper divided into twelve heads, the

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details in the middle divided into the same twelve heads, and the conclusions divided into the same twelve heads. That made it most useful and convenient for analysing and for the preparation of notes for the discussion. He also wished to congratulate the Author on the extreme patience which characterized the work which formed the subject of the Paper, and the way in which it had been carried out. Having said those pleasant things, he might perhaps be permitted to criticize, because he did not agree altogether with the Author in the results of his investigations, and he thought he could put one or two arguments forward which would indicate that the investigations might be carried a great deal further with advantage.

In looking at a Paper of that kind, one naturally looked first of all for the direction in which it was going to help the ordinary engineer, to ascertain in what way it would help him to pay a larger dividend—because that was the practical and commercial side of it—and he failed to find much in the Paper which would be of immediate help in that direction, the main conclusions arrived at by the Author being, he thought, well within their existing knowledge. Taking, for example, the Table as to the speed at which finishing cuts could be taken on a lathe turning steel, in the first instance it was, on small work at all events, uncommon nowadays in good practice to take finishing cuts with a tool on steel in a lathe, the better practice being to finish by grinding. On large work it was perhaps essential to use finishing cuts, but most engineers endeavoured to do away with them wherever they could. On small work, finishing with a lathe tool was undesirable. In future they would probably grind the larger work; but on small bar work nowadays where they did not grind they usually finished with a tool that was steadied by a plain or preferably by a roller steady. He was speaking of the very large quantity of steel work which was made from the bar upon a turret-lathe. In such work the question of what the tool did with regard to finishing was quite unimportant, as it was not the tool that did the finishing but the steady which burnished or rolled the surface of the work. The maximum speed at which finishing mild steel

could be done was given in the Tables in the Paper as 48 feet. He thought that, on a bar lathe using a roller steady tool, a finishing speed of 48 feet per minute would be looked upon as somewhat behind the times. As a matter of fact, in experiments which had been made by his own firm and recorded, finishing cuts had been taken quite successfully at a cutting speed of approximately 295 feet per minute.

With regard to the durability of tools on such work, and on all work as a matter of fact, he thought they should take into account the fact that durability was seldom the determining factor. When they were using a lathe they were not trying to save their tools. If they were boring a marine cylinder it was perhaps necessary to take a cut completely through the cylinder without changing the tool, but on ordinary work they were trying to get output, and it frequently paid in such cases to use the tool up quickly and to have suitably ground tools all ready and means for replacing the worn tools quickly. He thought the question of the durability of the edge of a finishing tool was only occasionally of great importance, and in the case of a roughing tool hardly ever of great importance. On the bar turret-lathe for work up to, say, $2\frac{3}{4}$ inches or 3 inches diameter, he thought it could be said that there was no single cut ever taken which took twenty minutes using modern tools, and if such was the case, the question of making a tool last twenty minutes was really unimportant, output, even at the expense of tool-durability, being everything.

Turning to the question of angles of roughing tools, he noticed in the Paper that the maximum rake tested by the Author in his experiments was 35°, and that the majority of good results were obtained with tools having a very much less top-rake than 35°. It seemed that no tool of the kind now used for turning bars on turret-lathes was tested. He desired to exhibit a wooden model which he had made three times the actual size to show the kind of tool he meant. The tool was a standard tool, that is, it was a tool used every day in turning mild steel. It did not represent the maximum top-rake that was possible, but the everyday top-rake that was used. The angle of the tool was 35°, which was all

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side-rake; there was no front-rake at all, and he did not think any tool had been tested by the Author which had side-rake only. The clearance which had been found advantageous was 7°, which, it might be noted by the way, was rather more than the Author's clearance, which was 5°. The tool represented by the model took a heavy roughing cut at 295 feet per minute, and he could give particulars of three cuts which were taken with the tool. It was a high-speed tool, the section being 1 inch deep by $\frac{3}{4}$ inch wide, and it reduced a bar from $2\frac{1}{4}$ inches to 1 inch at 500 turns per minute, equal to 295 feet on the outside of the bar, 44 cuts per inch, and it removed 32·3 cubic inches, which was equal to 9·04 lb. of steel per minute. That was actually measured. It might not agree with the calculation, because the machine usually slowed down a little with a heavy cut. Similarly reducing a $2\frac{1}{2}$-inch bar to $\frac{3}{4}$ inch at 500 turns, 262 feet per minute and 34 cuts per inch—which was coarser—it removed 36·11 cubic inches per minute, that is, 10·11 lb. Reducing a 2-inch bar to 1 inch at 256 turns per minute, that is, 134 ft., 20 cuts per inch, it removed 27·68 cubic inches per minute, which was equal to 7·75 lb. It seemed to him that that was a kind of tool that ought to be experimented with, because it was certainly capable of higher output, with, he thought he could say, less power than all the tools which formed the subject of the experiments described in the Paper.

He thought it was a mistake to speak about the height of the cutting edge of the tool, as height had nothing to do with it. If the lathe were turned upside down and bolted on to the ceiling, what was low when it was on the ground was high when it was on the ceiling, and vice versa. What ought to be considered was the relation between the various dimensions of the tool and the line joining its point to the centre of the work. When the height of a tool was increased, they simply increased the top-rake and reduced the clearance, and when they lowered the tool the top-rake was reduced and the clearance increased. It was very deceptive to say that a tool should cut high or low. A tool should cut neither high nor low. Its angles should be proportioned for the work it was doing, and that was all that could be said about it.

With regard to Subject 7 (page 793), he thought it was most interesting to know that the Author's experiments had shown there was no advantage in forging tools, because that conclusion supported very strongly the use of those modern tool-grinding machines which produced tools direct from bar-steel, and produced them very much more quickly, more cheaply, and generally more accurately than when they were forged. He thought that was a proof which was badly needed by the engineering trade.

There was one other matter on which he desired to confirm, from his own experience, one of the Author's conclusions, namely, Conclusion 9 (page 820), the relation between the cutting speed and the horse-power or the energy used in the cut. Some years ago he had had a hydraulic indicator made for measuring the torsion on a tool. It consisted of a spindle mounted on ball-bearings with a lever attached to it, and a hydraulic cylinder and pressure-gauge for measuring the torsional pressure. There was another cylinder for measuring the end-pressure and another gauge. It was found that in drilling, in tapping and in turning, there was no appreciable difference in the torsion required to turn the drill round or the tap round or to turn the work round against the turning tool, no matter at what speed the work was done. He certainly found it difficult to believe at first, because he could not see how a tool could work more rapidly against the work unless it had a harder push, and a harder push appeared to him to indicate that there must be more energy put into it, but the measuring instruments did not indicate any more energy at all.

Mr. R. J. A. PEARSON, O.B.E., said that, after considering the Paper and the results which had been put before The Institution in connexion with it, he thought it would prove of great interest if some investigations of a similar nature could be carried out on those finishing tools which had to produce repetition work. The broach was a good example. Broaching was becoming every day more common, and in the mass production which it was hoped would take the place of a good many of the old methods of work, the broach would be one of the leading tools used. In the case of

(Mr. R. J. A. Pearson, O.B.E.)

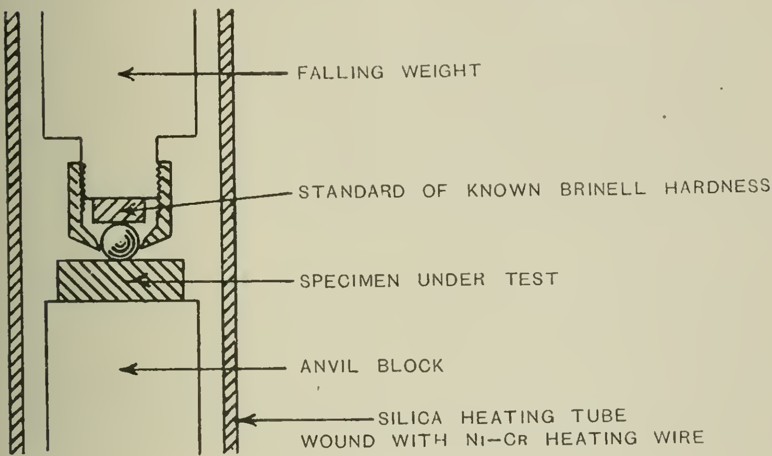
a broach, it was required to produce, say, 500, 1,000, 10,000 or 50,000 parts which were similar to one another within certain small limits. Gauging arrangements were provided and the work was continuously produced with a broach until the inspector threw some of the work out. It seemed to him there was room for a great deal of research in that direction. The value of good broaching was so largely reflected in the cost of putting the work together, doing away with fitting, doing away with those expensive hand operations which many engineers hoped would largely become a thing of the past, that if some reliable data could be obtained to guide those who were extending broaching, it would be of the greatest assistance. An intricate broach cost a great deal of money, and it was extremely desirable that it should be made on lines that would give the best results, that would give the best endurance and that would in every way economize on the cost of the finished article.

In round blind holes in which broaches could not be used, reamers were frequently used in their place. Reamering again was an operation in which it was desired to produce as far as possible a number of articles which were in very close similarity one to another. He had carried out a large number of experiments in connexion with reamering, but they were not yet in a sufficiently advanced stage to put before The Institution. There was one particular point in connexion with reamers which he desired to mention. The ordinary adjustable reamer usually had a square cutting edge somewhat of the shape that a fitter used for scraping. He remembered that in his apprentice days he used to do a considerable amount of scraping. Nowadays if the manager saw much scraping he dismissed the foreman. A reamer was somewhat of the nature of a scraper, and he found in his preliminary experiments that by putting a rake on the reamer very much better results, so far as finish was concerned, were obtained. He was not prepared to say what the results were in regard to durability, as to the number of pieces that any one given reamer would turn out before the work fell outside the limit allowed, but he hoped to be in a position to give that information within a reasonable time.

He was, however, pursuing with very close interest the question, with reference almost entirely to finishing tools which were required to produce the same result over and over again within certain fine limits.

Mr. J. Ferdinand Kayser (Sheffield) said that up to the present no connexion had been shown between the Brinell

Fig. 92.—*Determining Brinell Hardness at High Temperatures.*



hardness of a high-speed turning tool and the cutting efficiency of that tool. That was because Brinell hardness of the tool had always been taken in the cold state. When the tool was at work its temperature was raised, and he had devised a small machine for determining the Brinell hardness at high temperatures. An impact method which eliminated any cooling effect of the ball was used. Fig. 92 showed the principle of the method. It depicted an anvil which was in a heating tube. The specimen under test was hardened, and then placed on the anvil and heated up. Then a falling weight which carried a ball was allowed to fall, and behind that was a standard of known Brinell hardness. Whatever the

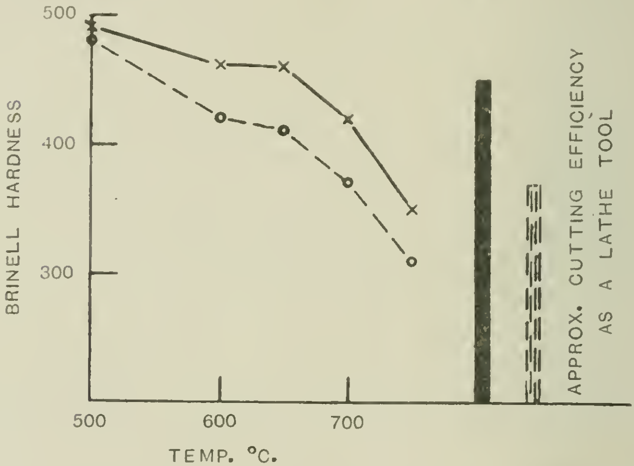
(Mr. J. F. Kayser.)

energy of the blow, the same amount of energy was put on to both the specimen under test and the standard, and, knowing the Brinell hardness of the standard behind the ball, from the dimensions of the two impressions formed, it was possible to calculate the Brinell hardness of the specimen under test.

He had dealt largely with two steels: (1) an 18 per cent.

FIG. 93.—*Cutting Efficiency and Brinell Hardness of Two Super High-Speed Tool Steels at High Temperatures.*

Full lines and black area C 0·6; Cr 4·0; Mo 6·0; Co 5·0; Ni 1·0; V 1·0.
Dotted lines and dotted area C 0·67; Cr 4·0; W 17·7; Mo 0·54; V 0·25.



tungsten steel with 1 per cent. vanadium and 1 per cent. molybdenum; (2) a cobalt-molybdenum-chromium high-speed steel containing about 0·6 per cent. of carbon, 6 per cent. of molybdenum, 5 per cent. of cobalt, and about 4 per cent. of chromium. He hardened the tungsten steel from an electric salt bath at about 1,300° C. (2,372° F.), quenched it in oil, and then tempered it at 650° C. (1,202° F.), which was generally assumed to be a suitable temperature for treating such steels. The cobalt-molybdenum high-speed steel was more easily hardened, because the hardening temperature was much lower. It was hardened at 1,120° C.

(2,048° F.), quenched in oil, and then tempered at 550° C. (1,022° F.). A very large number of cutting tests had shown that of the two steels the cobalt-molybdenum high-speed steel was undoubtedly superior as a turning tool. Fig. 93 showed the results obtained in graphical form. The results showed that the Brinell hardness of a high-speed tool at high temperatures was undoubtedly related to its cutting efficiency.

Another question that had been raised was the forging of tools. Metallurgically it was always considered that a tool-nose was forged in order to put more metal into the tool-nose and so enable a section of, say, ½-inch square to be used as if it were ½ inch by ¾ inch, but no greater gain in cutting efficiency was thereby obtained, other than was obtained by using a tool of greater cross-section; in fact, all high-speed steels made quite efficient turning tools if used in the cast state; that is, it was not necessary to forge them at all, but if they were cast to shape and then annealed and hardened they were quite efficient. [*See* page 885.]

Mr. E. G. HERBERT said the various subjects dealt with in the Paper were all of considerable interest to engineers. Some were of particular interest to himself, because of their bearing on his own work, and because six years ago, when Dr. Ripper was in Manchester, he urged upon him that some attention should be paid to finishing cuts or as he (the speaker) preferred to call them, fine cuts. As Mr. Burley pointed out, finishing cuts had to some extent been replaced by grinding, but fine cuts would always be necessary. There were other cutting operations besides turning, to which grinding could not be applied. Moreover, it was his belief that from results produced by fine cuts a great deal could be inferred as to the behaviour of the tool under very different conditions. A number of tools used by engineers always took fine cuts and often at very low speeds. He would only instance the broach, the reamer, and the file. Information about the behaviour of steel under those conditions was of vital interest to the makers of such tools.

Turning to the information given in the Paper, he had very

(Mr. E. G. Herbert.)
little to say with reference to the finishing cuts. Tests were made to ascertain the highest speeds at which a good finish could be produced, but these speeds seemed to him exceedingly low; a finishing cut at 17 feet per minute was scarcely modern workshop practice, and that was given as the maximum for high-speed steel tools. The shape of the tools must have been such as to produce chattering, and a narrower point or different shape of tool would have given a good finish at much higher speeds.

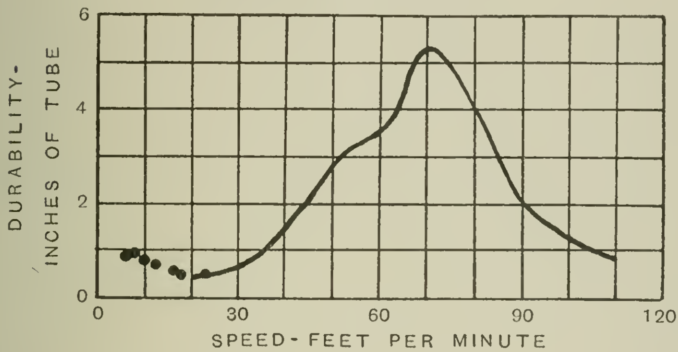
As to the durability curves on page 768, the point which struck one at first sight was the exceedingly low durability of the tools with such a fine cut and such a very low speed. The carbon-steel tool gave out after 20 minutes with a depth of cut of $\frac{4}{1000}$ths and a speed of 23 feet, and the high-speed steel gave out apparently after about 16 minutes at 30 feet. What would happen if the speeds were raised to those used in the workshop, say 100 to 120 feet? If the curves were continued to the left in the direction in which they were apparently going, and in which Mr. Burley and Dr. Ripper said they must go, they would strike the zero line somewhere about 40 feet. One would be led to the conclusion that neither a high-speed steel tool nor a carbon-steel tool would cut at all at the speeds used in the shops, because they would have zero durability.

He wondered if it occurred to the Author to compare the diagram on page 768 with the statement on page 760. On the former they found two tools almost done for, at 20 feet and 30 feet, and on page 760 the same two tools were cutting at 125 feet on the same bar. Yet they were assured there was no increase of durability as the speed increased. It would be very interesting to have the Author's opinion as to the form which these curves would take between the points at which they left off and the speed of 125 feet. Had he made any durability tests on those higher speeds? If not, why not?

It was stated that the original research was undertaken to investigate whether the results—the "remarkable results" they were called—obtained on the Herbert testing machine could be reproduced on the lathe. They were told those results could not

be reproduced. It might be useful if he recalled to mind the "remarkable results" referred to. The curve shown, Fig. 94, was produced on the Herbert tool-steel testing machine, which was really a lathe in which a cut was taken on a tube of 60-ton steel with a very fine feed, the durability of the tool being measured by the number of inches of tube which it would turn away before it arrived at a standard degree of bluntness. The remarkable results referred to were, a very low durability at low speeds, an increase of durability

Fig. 94.—*Curves produced on Tool-Steel Machine (Herbert) showing durability of Tool.*



as the speed was increased, and then a falling away. In order to show the exact bearing which the Author's tests had upon his results, he had plotted Mr. Burley's observations on the same diagram. The black dots indicated the results of Mr. Burley's tests, undertaken to criticize that curve. In plotting Mr. Burley's results he had had to make a slight correction because his durability was measured by output and Mr. Burley's by time. It was merely a matter of convenience which method was adopted. Of course it was perfectly easy to translate time-durability into output-durability by calculation. He had done so and he had taken such a scale in plotting the results that Mr. Burley's test at 23 feet lay on his curve at 23 feet. Of course he did not wish it to be inferred that the durabilities were equal at that speed. They were dealing merely with changes in the degree of durability and the direction

(Mr. E. G. Herbert.)
in which the changes took place. As to the huge increase of durability which he had observed when the speed was raised from 20 feet to 70 feet, Mr. Burley and Dr. Ripper denied its existence, but offered no evidence in support of their denial. That such an increase of durability did actually take place there was a great deal of evidence, which had been accumulating for some years. Mr. S. N. Brayshaw, in commenting upon a Paper read by him (Mr. Herbert) before the Iron and Steel Institute, wrote as follows :—

"The following might serve as an actual example of what occurred in his own works. A large quantity of tool-steel bars ⅞-inch diameter were being turned up and for some time the machines ran at 195 revolutions per minute, which gave a cutting speed of 38 feet per minute on the largest diameter. The tools dulled very quickly, and had to be re-sharpened on an average once every forty-five minutes. The speed was then increased to 330 revolutions per minute, giving a cutting speed of 65 feet per minute, other conditions remaining the same. The consequence was that the life of the tools was increased to about three hours, which meant an increase of nearly sevenfold in the actual work done by the tool for every sharpening."

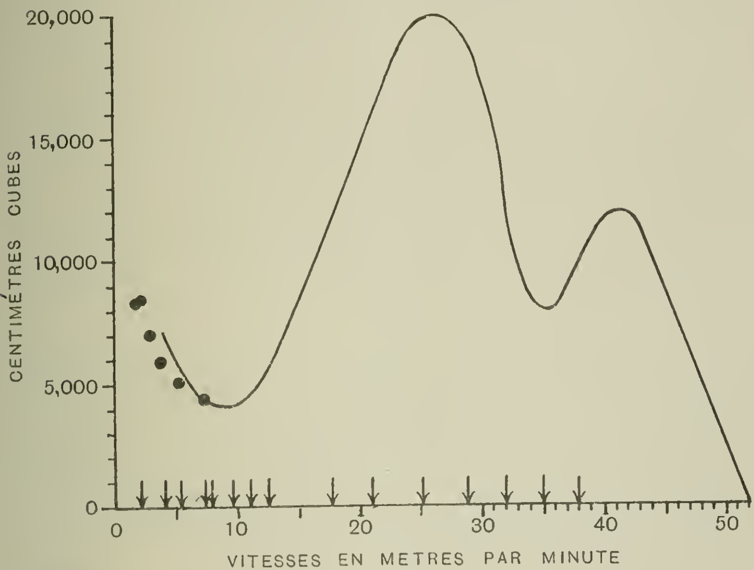
The second witness he would bring forward was Captain M. Denis, of the French Artillery, who had a tool-steel testing machine installed at the Puteaux Arsenal near Paris, and carried out a very elaborate series of experiments on the testing machine and the lathe side by side, in order to correlate the results obtained from the two machines. He had published a large number of curves obtained from both, and he had also got out very full tables, and had produced a special slide-rule, by which he claimed to be able to predict from the testing-machine curve how a given tool-steel would behave under any cut, feed, or speed, on the lathe.

One of Captain Denis' curves he now submitted to the members for examination, Fig. 95. It was produced on the lathe, not on the testing machine. It would be seen that the general form of the curve was very similar to that produced on the testing machine; there was the usual huge rise of durability as the speed was increased and then a falling off.

He had again plotted Mr. Burley's observations on this second curve to show exactly the bearing they had on the results Mr.

Burley set out to criticize. They lay on the peculiar upturned portion of the curve. That, he thought, was not of much practical importance, but it had considerable interest for him, because, as the result of some breaking tests which he carried out on specimens of tool-steel heated to various temperatures, he was led seven or eight

Fig. 95.—*Curves (produced on Denis Lathe) showing durability of the Tool.*



years ago to anticipate that just such a rise of durability with decreasing speed must take place at that point. He made a great many experiments on a tool-steel testing machine, lubricating with freezing mixtures and various things of that kind, but he entirely failed to find it. Captain Denis showed it on most of his lathe curves and Mr. Burley showed the same thing.

The arrows indicated the speeds at which Mr. Burley carried out his first series of tests, which went up to 116 feet per minute. It was rather unfortunate that when making those tests Mr. Burley did not measure the durability. It would have been very

(Mr. E. G. Herbert.)
interesting to know what the durability of the tool was at all these speeds which were on the curve and not off it. The case as shown by these curves was at issue between Mr. Burley, Dr. Ripper, and himself. The members would be able to judge which was likely to be right. If Mr. Burley were right, the characteristic durability-curve of the tool was given by drawing through those dots a line which apparently came to an untimely end somewhere about 40 feet per minute, and they were assured there was no resurrection. It was a very sad state of affairs for all of them. If Captain Denis were right, they might continue to use their cutting tools at the speeds at which they were now using them. He proposed to ask the Institution of Mechanical Engineers, through its recently appointed Cutting Tools Research Committee, to undertake an investigation into the subject, "What are the changes of durability which occur in a lathe cutting tool, taking a fine cut, when the speed is raised from a low value to the highest at which the tool will operate."

Mr. DEMPSTER SMITH, M.B.E., remarked that the methods adopted by the Author for measuring the cutting capabilities of finishing tools were similar to those employed by Mr. H. Iinoya and himself and also by Professor R. Poliakoff. The results of these trials were recorded in the Proceedings of the Manchester Association of Engineers 1914–15. The experiments made by Mr. Iinoya and himself had for their object:—

First, to determine the quality of finish produced with stiff finishing tools of carbon and high-speed steel at different cutting speeds.

Second, to obtain the extent of surface machined by these tools at different cutting speeds,

(*a*) within what would be considered a "good finish," and

(*b*) before the tool attained a pre-determined degree of bluntness.

In these trials tools having a cutting angle of 65° and clearance angles of 2° were used. The cut was $\frac{3}{1000}$ inch deep and traverse of $\frac{1}{20}$ inch per revolution of the work. A mixture of soap and water was used as a cooling agent.

With regard to the first of these objects, it was found that a certain quality of finish accompanied each cutting speed, and this finish, which was independent of the tool steel used, depreciated as the speed increased up to 80 feet per minute. At low speeds (10 feet per minute) the surface was smooth and highly polished, but this fell off in quality as the cut progressed, and ultimately the tool began to pluck or tear the surface of the work. Below 30 feet per minute the plucking took place over large patches of the surface, but at higher speeds the plucking was confined to smaller areas. At about 60 feet per minute there was practically no polish, the surface being a dull grey colour, and had the appearance of having been sand-blasted, yet it felt fairly smooth. An examination under the microscope, however, showed the entire surface to be torn, and whilst this was also the case at lower speeds, it was not so apparent.

With regard to the extent of surface machined up to the point where plucking usually commenced, it was found that this generally increased with the speed of cutting up to 120 feet per minute, beyond which the trials were not carried. At a speed of 10 feet per minute a high-speed steel tool machined about 150 square inches and 300 square inches at 120 feet per minute. Between 30 and 90 feet per minute tools of carbon-steel gave slightly better results than those of high-speed steel. Taking $\frac{1}{1000}$ inch as the predetermined wear, the surface machined by the high-speed steel tools increased from 180 square inches at 20 feet per minute to 800 square inches at 45 feet per minute, whereas the carbon-steel tools only machined 100 and 600 square inches at these speeds.

The Author did not give the duration of cutting or extent of surface machined and considered smooth in the trials given in Tables 1A–1C and 2A–2C (pages 762–3). Similar data were lacking for the trials recorded in Table 3 (page 765).

The Author had not accounted for the rapid fall in the performance of tools having side top-rakes of 25° and over when operating upon mild steel as shown in Fig. 76 (page 771). It seemed very probable that this was due to the extreme cutting edge being broken off as the tool entered the work. He did not think the

(Mr. Dempster Smith, M.B.E.)
Author intended the equation: $R = 40 - 0 \cdot 6T$ on page 773 to hold good for all values of T (tensile strength of the steel), since this would result, in the case of a heat-treated shaft which had a value T of about 80 tons per square inch, in R having a negative value of about 8°, which was not practicable. In a Paper, "Experiments with a Lathe Tool Dynamometer,"* Dr. J. T. Nicolson had shown that the cutting force was independent of the cutting speed, and decreased as the cutting angle decreased or top-rake increased. These results had been confirmed by other experimenters, so it might be accepted that the net horse-power for a given cut, material, etc., increased in direct proportion to the cutting speed. He agreed with the Author in that the colour of the cuttings was not necessarily an index of the cutting efficiency. Many factors other than those mentioned affected the colour.

He believed he was responsible for the further inquiry by the Author into the effect produced by a change in the nose-radius of the tool. In the Paper on this subject by Prof. Ripper and the Author, it was shown that a large increase in the cutting performance was obtained with an increase in the cross-sectional area of the tool. Except a statement to the effect that the tools were geometrically similar, no mention was then made of the nose-radius associated with each section, and it appeared that the Authors had either overlooked, or were unaware of, the effect due to a change in the nose-radius. Anyone reading the Paper would have attributed the improvement to be due to increased cross-section, and thanks were due to the Author for carrying the investigation further and separating the conclusions due to these two factors.

In order to study the effect due to a change in either of these two factors, the actual results rather than the calculated values in Table 7 (page 783) and Fig. 84 should have been given. From Table 8 it would be seen that with an increased ratio of tool section of about 6 to 1 there was an average increased output of 45 per cent ($\frac{1}{8}$-inch and $\frac{1}{4}$-inch nose-radius), whereas with an increased

* Proceedings, I.Mech.E., 1904, page 883.

ratio of nose-radius of 2 to 1 the output was increased by about 18 per cent. For the same cross-section ratio, the increase in output given in Table 9 (page 787) was only 18 per cent, whilst for the above nose-radius ratio the output was 45 per cent, so that the results given in Table 8 and 9 were just the opposite way about. Apart from the small range of nose-radius, information further than that given was required before the independent effect of nose-radius and cross-section could be determined. The Author was therefore not justified in taking either result or the average of such results, and consequently expressions (4) and (6) could not be accepted as correct. When the first Paper was presented, exception was taken to these expressions on other grounds.

With regard to expressions (3) and (5) which gave the permissible cutting speeds for carbon-steel tools, the Author had produced no experimental evidence in support of the values taken for tool-section, nose-radius, and cooling agent. The values for these factors obtained in trials with high-speed steel tools could not be applied to carbon-steel tools. If the Author had no such experimental data and the values had been simply assumed, then this should be clearly stated in the body of the Paper.

Colonel R. E. B. Crompton, C.B., R.E., said it was with considerable temerity that he addressed the members on the questions dealt with in the Paper. In the first place, he was an old man and felt that everybody should criticize in a kindly spirit. Bearing this in mind, although he thanked the Author for the amount of work that had been put into the Paper, he thought that the Paper in itself was in a sense a dangerous one, as it led, or had a tendency to lead, to conclusions which he believed to be false. The present was an age of high-speed steel. Dividends were paid by mass production carried out in the least costly way, and that mass production in a great many instances depended on the speed at which material could be removed. A statement had been made in the *Daily Mail* within the last few days—which was illustrative of the interest the question was supposed to have for all engineers—that a wonderful new high-speed steel had been produced. Steels of the nature

mentioned had in common with other well known steels very high cutting qualities, but he desired to confine his remarks to a different branch of subject.

Many of those present knew that he had been carrying on experimental work initiated by the late Sir Frederick Donaldson, whose death all the members of The Institution—none more than himself—regretted so greatly. Sir Frederick Donaldson incited him to spend a great many hours in studying the question of the distortion of steel in hardening, which caused the pitch errors of screwing taps and thus made screws not interchangeable. This was a great difficulty, as the nuts did not assemble with the screws; and it was very largely a question of distortion in hardening. He had worked at the subject for 14 years, and during that time he had acquired a certain amount of useful knowledge. Mr. William Taylor knew very well the nature of that work, which was small scale work. He worked with a precision lathe from which he could turn out very correct work. But in carrying out that work, and in attempting to produce a formula for the heat treatment of non-distorting steel, he had required a good standard of the degree of hardness necessary for efficient cutting. When he began to investigate the subject, he came across what were to him some surprising facts. These showed that Mr. Herbert was right (page 836), and that the Author was wrong in saying that the smoothness and good finish of the machined surfaces was limited to such low speeds as 38 feet a minute, and so on. But he would not have dared to quote the figures he was about to give, if it had not been for the remarks Mr. Vernon had made. Mr. Vernon had done on a large scale what he (Colonel Crompton) had done in his laboratory. That is, he showed that there were high speeds at which far more cylindrical and accurate turning work could be obtained than at lower speeds. This apparently had not been noticed by the Author, and he thought it was necessary to bring the point before the Meeting. Using steel which he believed resembled very closely the steel referred to in the *Daily Mail*, but which contained cobalt as a steadying agent, in addition to molybdenum, he had cut and finished to a good surface the most difficult steels—steels

containing 4 per cent of nickel, 0·4 per cent of carbon, 1 per cent of chromium, and 0·8 per cent of manganese. This was a most difficult steel to cut; more difficult than any of the high-carbon tool steels which contained 1·3 per cent. of carbon. But he had turned bars of this steel 2 inches diameter and produced a good surface—nearly equal to that produced by grinding—at 180 feet a minute. He dared not have quoted such a speed to the Meeting if it had not been for what Mr. Vernon had said; he would have feared that the members would not have believed him, but he too believed it himself now, after hearing Mr. Vernon. He exhibited a small bar which he had brought with him that evening to show the members. They probably would not believe that it had been finished at about 84 feet a minute and had not been polished, and yet it was one of the hardest tool-steels in existence. Incidentally, he might say it did not show more than 0·0008 inch length change per inch by hardening, so that the difficulty had been solved of producing a tap steel which practically did not change. (A Member inquired what depth of cut and feed Col. Crompton used). The depth of cut was practically the same as one of those quoted by the Author—he thought about 0·003 inch—and the feed was 150 per inch—a very fine feed. If that small piece of work were examined under the microscope, it would be seen that it had a fine but very shallow thread on it. It was so fine that it could not be felt by the hand. The thread was so shallow that it could be polished out in a few seconds by rubbing it sideways with emery paper.

Mr. W. H. Patchell inquired whether the specimen had only been turned. It looked as if it had been filed.

Colonel Crompton replied that the specimen had not been filed. He also exhibited a large 2-inch bar, showing a rough cut and a finishing cut. No attempt had been made to put any polish on it, and it was just in the condition in which he had chopped away at it at the high speed of 150 feet per minute. The advantage of working on a small scale was that he was able to corroborate a great deal of what Mr. Vernon had said about the curious fact

that the torque required to make the cut was independent of the speed; but the actual torque required seemed to be approximately constant throughout a speed range from 30 to 200 feet a minute. It was a very remarkable fact; but he had put a delicate ammeter in circuit, in accordance with Mr. Roberts' suggestion at the previous discussion, and he had thus been able to observe and corroborate all that Mr. Vernon had said.

Personally, he did not know what Mr. Vernon would say, but he thought the limiting factor when using very high speeds had not been the wear of the tool, but how to avoid chatter, and yet not a word was said in the Paper about chatter, which was the bugbear of the lathe man when he was dealing with high speeds. Much was said about the question of the shape of the nose, the angle of rake, and so on, but not a word was said about the chatter-determining factor which limited the speed when the high speeds to which he was referring were used. He had not previously heard of such high speeds as Mr. Vernon had spoken about, but he believed that what he had said was correct, because with the comparatively small scale appliances that he (Colonel Crompton) had used he had himself reached a speed of 200 feet a minute.

He desired to add a word to what Professor Ripper had said in regard to the loss The Institution had sustained in the death of Mr. Wicksteed. Mr. Wicksteed was a personal friend of his, who had assisted him when he was a young man, organizing and developing the firm of Crompton's, and he was a man whose loss he felt very greatly.

Mr. G. W. Burley, in reply, having thanked those members who had taken part in the discussion, said he did not expect that everybody would agree with all he said in the Paper. In reply to Colonel Crompton's remarks (page 844), he wished to point out that he had not been able, within the small compass of the Paper, to deal with everything, and the question of chatter was one of the things he left out purposely. In response to Professor Ripper's suggestions (page 825), he would get out a Table of speeds which he would include in his written reply. Owing to the short amount

of time available, he would prefer to communicate the remainder of his reply to the discussion in writing.

Discussion in Manchester, 23*rd December* 1919.

The Chairman (Professor G. Gerald Stoney, F.R.S., *Member*) said the Paper was of the greatest interest to engineers. He would like to ask whether any tests had been made as to what form of tool gave the least chattering. What often limited the speed and cut on a job was the stiffness of the lathe and of the job; and an important point which he never saw dealt with in any of these investigations, was what form of tool was able to take the heaviest cut at the highest speed on a light job liable to chatter; in other words, what tool gave the least chattering.

A minor point was that it would be a great convenience if the shape of the tool was such as to break up the shavings into short bits instead of having them in long coils. If the tool broke up the shavings into short bits, they were quite easily collected and carted away while the long shavings had to be broken up.

Mr. Daniel Adamson (Member of Council), in opening the discussion, said the Author referred on page 756, in paragraph 8, to the influence of the cutting edge upon the net amount of power consumed in cutting. It occurred to him that the durability of the tool was much more important than the amount of power consumed, and it was also, from the point of view of experiment, much more difficult to ascertain. Durability implied better output from the machinery and less time lost in changing the tools.

The effect of variation in the material which was being cut was even more important in a workshop. Perhaps it did not come within the province of the Paper but he hoped to see investigators

(Mr. Daniel Adamson.)
give some attention to that question. For example, his firm had a large steel casting on a planing machine (which was fortunately fitted with a variable-speed drive) a few years ago, when they found that for a width of about 18 inches across the face a speed of 14 feet (which was the lowest they could get) was much too fast; after that portion was passed over they could run at 60 feet per minute quite satisfactorily. Some guidance to workshop managers on that very troublesome question as to why one part of a casting should be so much harder than another and how to get over the difficulty would be most valuable.

Paragraph 6 (page 756) referred to "The influence of height of the cutting edge upon the cutting efficiency of high-speed roughing tools." Such a variation was merely a variation in the front clearance and the top-rake of the tool. It would have been very interesting if the Author had told them whether the raising of the tool affected its durability in the same manner as reducing the front-rake clearance angle, as would be expected theoretically. If they referred to Fig. 85 (page 789) and the top of the following page they would observe that Mr. Burley explained that the effect of raising the tool $\frac{3}{8}$ inch above centre on a 10-inch bar was to make the clearance angle only half a degree instead of 5°, or $9\frac{1}{2}$° if it were placed a similar amount below the centre. Up to now his own theory had been that it was immaterial where the tool was placed if those actual angles were similar, and the only effect that the Author had experienced apparently was that he found that a tool with a front clearance angle of half a degree and corresponding top-rake angles of an increased amount, gave a slightly different power consumption; but would a tool placed on the centre with a front clearance of half a degree and a top-rake of $15\frac{1}{2}$° have given similar results? The Author had missed an opportunity of answering that question. In his own workshop they preferred to set the tool below the centre rather than above the centre for the reason that, if there were any slight spring in the lathe, the tool sprang out of the cut and so relieved itself, whereas if it were above the centre (as illustrated in Fig. 85) the tool might pluck in on heavy cuts and cause trouble.

One interesting feature that readers of this Paper ought to note was the reference on page 760 to the cutting speeds at which "building-up on the cutting edge" took place. There was room here for careful investigation as to the limiting conditions for this phenomenon.

The choice of rake angles referred to at the bottom of page 769 "to make the cutting edge AB horizontal in every instance" ought not to be overlooked by future investigators, as elimininating one of the many variables concerned in this many-sided problem of lathe cutting tools.

One omission from the Paper was that no description was given of the small lathe fitted with variable-speed mechanism. Reference was made to a previous Paper, in which the large lathe would be found to be fully described, but it would be a valuable addition to this Paper if short descriptions of both the lathes were included. The machine in which the tool was being tested was a very important factor in judging the results obtained, and the question of "chattering," which had been raised by the Chairman, would certainly be affected by the stiffness of the lathe which was being used.

. On page 758 the Author referred to tests of finishing tools. He would suggest that the piece operated upon—2 feet 6 inches length by 6 inches diameter, divided up into ten different sections—was much too small to give any confidence in the results obtained. For instance, nothing could be ascertained from such a small piece as to the length of time during which that finish would be maintained. He found nothing in the Paper to guide them upon that point. If Fig. 74 (page 768) (which was taken from tests on the bard steel test-bar Z) bad been drawn for the plain carbon tool operating on mild steel bars as Fig. 72 (page 764), they might have obtained some guidance as to how long, with the given tools, the desired finish was maintained. Up to the present the information before them was not sufficient to enable that to be done. That statement was subject to the Author's explanation or correction.

In Fig. 73 (page 766) a method was shown for testing the finish

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or comparing the finish obtained by using a cast-iron brake. He thought that the Author had missed there a favourable opportunity for making quite a valuable test of the surfaces he obtained. In practice, except perhaps for brakes, they never used dry cast-iron bearings on a steel shaft. If the portion called "Brake" in Fig. 73 could have been made of gun-metal and properly lubricated, the conditions would have been more like ordinary practice, and the Author might have obtained most valuable information as to the behaviour of the various "finishes" on pieces of shaft in actual bearing practice.

On pages 761–2 a comparison was made between plain carbon-tool steel and high-speed tool-steels on finishing cuts, and they were shown to be very similar in result in that they would all run up to about 48 feet per minute and give what the Author called satisfactory or smooth finish. But these were tools used on what one would call water finish, and in his own shop the opinion was that carbon-steel was generally more suitable for that kind of finish than high-speed steel. He thought the Author in his abstract did refer to the use of high-speed steel with very fine cuts and traverses. From experience gained in his own practice he would suggest that it gave a very good result for ordinary push fits to run at a high speed (say 150 feet per minute) with a fine traverse (about 80 per inch) and a fine cut (about one-sixty-fourth of an inch) and not touch the shaft afterwards by file or by grinding or in any other way, but leave it as it came from the tool.

Fig. 74 (page 768) would be much more valuable if a tabulation of the results upon which it was based had been given, and that applied to many other diagrams in the Paper. It was really insufficient for a fair judgment merely to see a small scale diagram such as the one shown. A Table showing the extent of the information upon which the figure was based would also enable readers to draw from it perhaps other conclusions than those drawn by the Author. It was given in some instances but not in the case of Fig. 74, where the objection to its omission was accentuated by a reference in the paragraph below the diagram to other results not recorded in the Paper.

On page 769 the Author spoke of "roughing tools," but as far as he could make out those were only used on cuts of $\frac{1}{8}$ inch by $\frac{1}{12}$ inch, which gave an area of cut only a hundredth of an inch or thereabouts, whereas in the Manchester experiments of sixteen years ago they got cuts up to four times that area, and perhaps three times the quantity of material was removed per hour. Some of the critics at that time said the Manchester Committee were only playing with the thing, and that the cuts were not big enough for any useful guidance in the shops even then. It was rather a pity that with such a large lathe as was available—18-inch centres, 10 feet between centres—larger cuts should not have been taken. He believed somewhat larger cuts were referred to in the Paper, but they were not very much larger than what he had mentioned. This point was referred to in the discussion on Professor Ripper's Paper* in Nov. 1913 comparing the scale of the Manchester experiments at that date together with Professor Ripper's experiments.

The Author referred to the effect of nose-radius. The same criticism of the small scale of the experiments applied here also in that the nose-radius used was about $\frac{1}{8}$ inch, which would have a very considerable effect upon cuts of only about $\frac{1}{8}$ inch deep. It would be usual, no doubt, to work entirely upon the curved portion of the nose, but upon cuts of greater depth on tools with larger nose-radius; so that any conclusions based upon a nose-radius of $\frac{1}{8}$ inch with a cut $\frac{1}{8}$ inch deep did not seem to be of sufficient importance really to base upon them such conclusions as mechanical engineers expected from a Paper of this class.

He did not like to criticize the title of a Paper; it sounded like a waste of words; but it was not until pages 769–70 were reached that they found out what the Author meant by "cutting power." In the middle of page 769 an explanation was given of what was meant by cutting power. They all knew that "power" to a mechanical engineer meant energy and was used in a different sense from that in which it was used here. What was really

* Proceedings, I.Mech.E., 1913, Figs. 57 and 58 (page 1168).

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meant was the capacity of the tool to remove material, whereas it might have meant the power taken in cutting by lathe tools.

With regard to page 770 he would like to protest against the "Speed-increment Test" being considered a really reliable way of obtaining the results desired by the Author, or his readers. It was very different from the practice in the shops. One did not generally start a job up slowly and go gradually faster until the tool was done. One made up his mind beforehand what was likely to be a reasonable speed and proceeded accordingly. The results obtained by a speed-increment test were very doubtful in this way; they might get a more favourable result in that the tool, being gradually warmed up to its work, might last better than it would have done if it started straight away from the cold.

Another objection to the speed-increment test was that the effect of speed on cutting was very much more acute at the higher velocities; the wearing out effect was very much more severe as the velocities increased. So for two reasons he suggested the speed-increment test was not as fair a test as the one referred to in Professor Ripper's original Paper as Taylor's method, of choosing a speed which might be expected to run something like twenty minutes. After all, they did not want to get an intentionally favourable result or unfavourable result from a tool; they wanted to get what would be a fair result in ordinary shop practice.

At the top of page 772 the Author used the phrase "associated with maximum durability and cutting power." If those two terms were not synonymous, as they appeared to be, the Author ought to explain what was the difference. If they were synonymous why repeat the same thing, unless he meant to say, "*or* cutting power."

It seemed elementary to say, as he read it on page 781, "that the durability of the cutting edge" depended "upon the form and general dimensions of the nose of the tool," rather than upon the power taken in the cutting. That had been elaborated by previous investigators in years gone by, and he was rather disappointed that some fresh ground had not been broken in the Paper. The Author stated that most of the questions laid down arose out of the discussions which took place in Manchester in 1913, and that

most of the work described was also done a few years back, but when a Paper of this kind was published it was disappointing to find that, as the Author acknowledged, new ground had been neglected. For example, turning to page 803, it occurred to him that in making the cooling and lubrication tests, Mr. Burley had missed a very good opportunity of comparing the effect of the soluble oil compound which he used with the effect of lard oil. He had all the apparatus there that was necessary and he might so easily have told them whether he found "the soluble oil compound diluted with water in the ratio of 3 to 1" equal to or better or worse than the lard oil which they were accustomed to use in pre-War days.

On page 789 it was stated that the tools were "hardened exactly alike." That was a very doubtful statement to make. To harden tools "exactly alike" required, he should say, someone more than mortal to attend to it properly. Perhaps Mr. Burley would explain how they tried to get them all alike. A short reference to the methods adopted would have been of interest to some of the members. On page 761 the Author referred to "ordinary oil hardening high-speed tool-steel" and to "water hardening variety of high-speed tool-steel." That might be new to some of them; it certainly was new to himself. A short description in the reply would be of interest.

It was difficult, if not impossible, to do justice to a Paper of this character by merely discussing points of detail as he had done, but he hoped that the questions he had raised would be dealt with in the Author's reply.

Mr. Edmund Simpson said he was pleased the Paper had been brought to Manchester to be discussed, because of the work in connexion with the subject which had already been done and which was still proceeding there. In all tests of the nature covered by the Paper it was absolutely imperative that the conditions should be as constant as possible.

He referred to the point raised by Mr. Adamson in regard to the hardening of the tools to ensure uniformity as far as possible.

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On page 787 the Author mentioned 15 per cent variation in the results of the tests; were they to understand that this variation applied throughout the whole of the tests made? If so, the tools had not been as consistent as could be desired before coming to conclusions such as those stated in the Paper. Many people, either from lack of knowledge or from carelessness, had hardened tools inefficiently and without any possibility of getting the consistent results necessary for making formulæ and arriving at reliable results on test. In connexion with the hardening of tools, variations in the cutting effect and durability, due to re-grinding after failure, had been found, but this should not be the case with proper heat treatment. He would therefore like the Author to indicate clearly whether the tools were specially hardened for each test and what steps were taken in the event of re-grinding to ensure the whole of the nose-point of the tool being consistent in its structure and quality.

The actual cutting angles given in the Paper corresponded very closely with those given in the reports of the Manchester experiments, but the Paper provided no evidence of the separate effects of side-rake as against the front-rake. Apparently the actual cutting angle was the angle that governed the power consumption and durability; and it did not follow that the combination of the front- and side-rake angles given in the Paper was going to give the best results. An increase in the side-rake and a reduction in the front-rake might give equally good results or perhaps better in some cases.

In regard to roughing, a statement was made in the Paper in regard to the colour of the turnings. It might be considered as proved definitely that the less the change in colour of the chippings for any particular speed and area of cut, the more efficiently the work was being done. The colour was very often increased by "crowding" of the chippings, that is to say, by the chippings coming off greatly distorted instead of approximating to the shape of the cut. That led to the question of the nose-radius of tools which had been referred to. Everyday practice, without experimental proof, was sufficient to indicate to most engineers

that an increase in the nose-radius was likely to give increased durability, but with the very small cuts which had been mentioned by the Author, not very much more was learnt. If a range of tests had been taken, say, from $\frac{3}{4}$ inch deep to $\frac{1}{8}$ inch deep with varying traverses, a much more useful and clearer statement of the case could have been given. Generally speaking, the effect of increase of nose-radius was to increase the length of cutting edge presented to the work, and so make the chips thinner and wider. Probably the same effect would continue with the deeper cuts, in which case it would show that the thinner the chip for a given area of cut the better the durability of the tools. It might also apply with a very shallow cut and a very coarse traverse, but the question of lathe or machine construction would enter into consideration on account of chatter which might develop.

Referring to Table 7 (page 783), to express the cutting capacity of tools in terms of the corresponding depth of cut for a life of twenty minutes seemed very unsatisfactory, and could not be considered reliable. A difference in depth of cut altered the conditions, and a different section and shape of chips would be produced. The influence of nose-radius of a tool could only properly be tested by comparison under identical conditions of depth of cut, traverse, speed and section of tool, and the section of tool under similar constant conditions and constant nose-radius. It appeared, therefore, that the Table was of little value.

With regard to the point where the tools failed not being very definite, mentioned on page 786, his experience was that the point at which the work in the lathe began to glaze was very definite, and could always be relied upon. It was the method used in the Manchester experiments of sixteen years ago and since.

With respect to tools being placed above the centre or below the centre he could not see sufficient evidence for the conclusions arrived at, the actual cutting angle being the governing factor. If the tool were put above the centre the cutting angle would be increased, in which case there would naturally be, with suitable front clearance, less power absorbed in cutting. The question was whether the same effect could not be obtained with the tool on the

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centre and at the same time have it more definite. If a tool angle of 70° or 80° were required, it could be got quite definitely on the centre without making any allowance for the height above. One generally considered that to get the heel of the tool well under the cutting edge, that is to say, to cut away as little as possible to give the necessary clearance, was an advantage, and on the centre it could be done much better than when the tool was above the centre.

With regard to the liability to chatter which had been mentioned, and quite apart from the strength of the work operated upon in the lathe, or the shape of the tool, he considered that was reduced by getting the sliding force on the tool greater than the surfacing force. This would lead one where convenient, to take a deeper cut with a small traverse rather than a shallow cut and a coarse traverse.

As to the forging of tools, as far as he could see or had experience, it should make no difference whatever to the efficiency of the tool. It should, however, be borne in mind that high-speed steel was of a very delicate nature and could easily be spoiled. Therefore, the more the preparation of the tool could be simplified the less the chance of error, and after forging, it was a safeguard to anneal before hardening, particularly in the case of complicated tools.

In Fig. 89 (page 807), the advantage of lubrication on a cut $\frac{1}{8}$ inch deep by $\frac{1}{12}$ inch was considerably greater than for a cut $\frac{1}{4}$ inch by $\frac{1}{12}$ inch on mild steel. That did not give much information, because the sectional area of the chip would have considerable influence on the benefit gained from the coolant. The larger the chip the greater the energy absorbed, and the greater the heat generated. One could conceive that a square chip, say, $\frac{1}{2}$ inch by $\frac{1}{2}$ inch, might not benefit much by the coolant, whereas a deep cut of fine traverse would benefit considerably by it.

Mr. E. G. Herbert repeated the remarks he had made at the Meeting in London (page 833).

Mr. Alfred Saxon said he was one of the Committee connected

with the Manchester Tool Steel experiments, and he had a feeling that as that research was being carried on with the aid of the Government Advisory Research Council, very little could be said about it that evening, but he took the opportunity to thank the Author for the great amount of trouble he had taken to bring this matter before them. The Paper represented a very wide field of research, and from the discussion that had taken place it looked as if that field were going to be very much widened. Some of them might think they knew something about it, having been engaged upon it for a few years, but the more it was discussed the further away some of the points seemed to be on which they thought they had acquired very good information.

The question of cooling by lubricants or coolants, as the Author termed them, had been referred to. He could remember that over forty years ago, in their own works, an apparatus was introduced in connexion with shafting turning, whereby a coolant was introduced under the tool, and the jet sprayed upwards to the cutting edge of the tool. He could hardly tell now why that was discontinued, but he would imagine that the finishing operation which had been referred to was, after all, the limiting point; because in turning shafting, there was a roughing tool used, and a finishing tool side by side, and in most cases two sliding saddles were employed, with four tools engaged in that kind of operation. Possibly it proved that, with regard to the roughing cut, the roughing tool stood all right, and the finishing tool was the limiting point. That seemed to be one lesson they had learned that evening; that in finishing material, if they finished accurately they were certainly limited in speed.

One thing he regretted, because it made the Author's description of the tools rather confusing—that they had not before them some samples of the tools used in the experiments. On page 759 Mr. Burley mentioned that the tool used on mild steel had a front-rake angle of 20°, and the other tool, the finishing tool for hard steel, had a front-rake of 10°. Later, on page 795, in describing another tool, Fig. 86, which was used, Mr. Burley spoke of a side-rake of 10°. He would suggest that in connexion with the

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particular rakes in question the Author might have described them as top-rakes rather than front- and side-rakes. His own experience with regard to either side-rake or top-rake had been that much less power was expended if that rake was increased. Why the Author should have used such a small rake on hard steel as 10° he could not understand, as he was certainly not convinced that this was the best angle for the purpose. During the War his firm had to turn quite a large number of hard howitzer tubes and gun-jackets, and the tool for the particular lathe where this operation had to be performed was ground with a considerable amount of side-rake, and that lathe would drive with less power and turn more off than with any of the other tools used.

They were all indebted to Mr. Burley for his Paper, and, if anything in it was subjected to criticism in Manchester in a friendly way, he hoped the Author would accept the criticism as it was intended. They had had to learn their lesson in Manchester in tool steel, and were trying to get through the programme they had arranged as well as they could. He hoped in all this research work each would do his best to help others as far as possible.

Mr. T. Bevan said he wished to emphasize the point which Mr. Adamson raised regarding the use of the speed-increment test for comparing the durability of tools. It seemed to him that the practical man in the shop, on reading a Paper of this description, where a figure was given of 50 per cent increase of durability of the tool under certain conditions over the same tool under other conditions, would immediately jump to the conclusion that the 50 per cent referred either to an increased speed, which could be used for the same life of the tool, or an increased life cutting at the same speed. The figures actually given in the Paper did not enable such a conclusion to be drawn. He thought the matter might have been placed more within the reach of the average practical man. The Papers which were given before The Institution should have that object in view as far as possible. In this case it could be done without a great deal of trouble when plotting the results, by changing the basis of comparison for durability. Undoubtedly the

speed-increment test had definite advantages from the point of view of experimentation, but it certainly would have been better in his opinion if the results had been plotted on the basis of variation of life with a constant cutting speed or variation in the permissible cutting speed with a constant life.

To show the effect of the suggested alteration, he took Table 18 (page 805), which showed the effect of different quantities of coolant on the cutting power of the tool, and he worked out what would be the uniform cutting speeds required, from the figures actually given in the Paper, to enable the tools under the different amounts of coolant used to stand for twenty minutes; that is, to have a life of twenty minutes. Taking the maximum flow of coolant, the increase in the cutting speed was 8 per cent. The figure given in the Paper as the improvement in the cutting quality of the tool for that quantity of coolant was 38 per cent. In his opinion that 38 per cent was rather misleading, and the 8 per cent, which represented the increased cutting speed which could be used for a constant life of twenty minutes with that amount of coolant, more clearly represented the difference in the cutting quality of the tool due to the use of the coolant. In that connexion it seemed to him that one could not add together the percentage increases in cutting quality as given in the Paper under different directions of flow. For instance, where two directions of flow were used—A and B—one could not add together the percentage increases and compare the sum with the percentage increase obtained by using the two directions of flow at the same time.

The experiments given in Tables 7 and 9 were apparently carried out on the same bar and therefore under similar conditions, and if converted to a basis of permissible cutting speed for constant life, say twenty minutes, the two results for the same section and nose-radius should agree, assuming that the relationship between cutting speed and depth of cut, as given in formula No. 6 (page 777), represented the facts correctly. Comparing those for a $\frac{1}{2}$-inch square section they got the same permissible cutting speed for a life of twenty minutes, but when the section was increased to $1\frac{1}{4}$ inch square the increase in the cutting speed, as obtained from Table 7,

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was much greater than that obtained from Table 9. It seemed to him that the reason for the discrepancy between the two must lie in the incorrectness of the relationship between the cutting speed and the depth of cut. In his opinion any formula which gave this relationship should include a factor depending upon the ratio of the nose-radius to the depth of cut. The effect of the nose-radius would be influenced by the depth of cut used. Possibly if a different depth of cut were used, but the ratio of nose-radius to depth of cut was taken as constant, the same permissible cutting speed would be obtained, or at least if a different speed were obtained, this difference could be taken as being entirely due to the alteration in the depth of cut.

Mr. R. Onions said that those who were connected with actual manufacture would ask themselves the question how far this Paper would apply to their own work, and the difficulty he saw was that most of these experiments were carried out on plain round parallel bars. In his own business they had to deal with crank-shafts, valve-spindles, spindles with collars, and also irregular cutting, such as in the case of connecting-rod ends. The tools illustrated would not, for instance, go up the side of the cheek of a crank and also go along the parallel portion. The tools might be very good for sliding, but it would be necessary to change them to do the surfacing or right-angled surfaces, and as the class of work usually met with in ordinary engine details did not call for long straight sliding, the constant changing of tools was an item to be reckoned with. He mentioned this because no reference had been made to the set-off tool similar to the Woolwich type, one capable of sliding and surfacing without the necessity of charging. It was a question whether such a tool would work as well as the straight nose as far as chattering was concerned, even though the cutting angles were exactly the same. Intermittent cutting also introduced severe conditions which widened the field for investigation.

Regarding the influence of the cross-section of the shank, it was disappointing to find it stated on page 820 that for an increase of 500 per cent. only 8·5 per cent increase in cutting power was

obtained. This statement wanted further confirmation, and it did not bear out the results obtained by the use of the coolant where an improvement in cutting qualities had been recorded ranging from 22 to 87 per cent, as tabulated on pages 812–14. The explanation might be that the increased sectional area was not brought sufficiently well up to the cutting point.

Another matter he had never seen referred to was the hollow-lipped tool, such as they were able to obtain with the Lumsden grinder. With such a tool one could convey a larger area of material close up to the cutting edge. With the tools referred to in the Paper they had a flat surface coming away from the cutting edge, but with a hollow-lipped tool there was a larger area coming up to the nose, and a better efficiency was obtained without interfering in any way with the chips that came away from the cutting edge.

Mr. G. W. BURLEY thanked those members who had taken part in the discussion for treating him so fairly. He would probably not have time to deal with the whole of the points raised in the remarks of the various speakers, and he would refer to some of them in his written reply.

Mr. Adamson referred (page 845) to the effect of the quality of material upon the speeds and also to the variations in the quality and texture of that material. In experiments of that kind they tried to have as many constants as possible, and in the tests where the mild-steel bar was used they tried to get mild steel as uniform as it could be made commercially. The hard-steel bar was one which was made specially with a view to keeping segregation down as much as possible. They were quite aware of the fact that variations did actually occur in the materials which had to be machined in the machine shops, and that those variations affected very greatly the cutting efficiency of tools, whatever their description or design. Mr. Adamson also referred to the possible connexion between durability and length of cutting edge of the tool, which was mentioned in the original Paper. It was pointed out that by so shaping the tool that the length of the cutting

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edge was increased, they were able to increase the durability of the tool.

In regard to the vexed question of the position of the cutting edge of a lathe turning tool, he did not want them to think, because he had dealt with it in the Paper, that he was pointing out any best way of fixing the tool. That was not his intention at all. But there were some people he knew in Sheffield whose business it was to test lathe turning tools, or rather tool-steels in the form of lathe turning tools, comparatively. Some of those people were engineers and set the tools so that the cutting points, or the main parts of the cutting edges, were considerably above the lathe centres. He really had that in mind when he did this work and wrote that part of the Paper; he merely wanted to find out whether the durability of the tool was increased by raising it or lowering it. In the Paper he merely presented the results of the experiments he had made with this object in view.

The original Paper contained a description of the small lathe upon which the tests were made, but he noticed that it was a very brief one, and if he could he would, in his written reply, do what Mr. Adamson asked, and amplify that description.

Reference had been made to the description of the tests in regard to the work with finishing tools in which test brakes were used. That matter did not appeal to him at all. He simply showed what had been done, some of the difficulties met with, and how attempts had been made to overcome them. With regard to Mr. Adamson's suggestion that they should use lubrication, he was afraid that that would upset entirely the conditions. What they thought was that the roughness of the surface of the work-piece might be measured by obtaining a coefficient related to the coefficient of friction. As they knew, the coefficient of friction was influenced by the mode of lubrication and the kind of lubricant used. It was found absolutely impossible to keep the surface quite dry, and since that introduced another factor they abandoned the method altogether. He might say that cast-iron was not the only metal which was used for the brakes; copper, lead, and even wood were also employed, but they could not make any use at all of the

results obtained, because they were so erratic and represented the case in which the extraneous condition of lubrication was involved.

Mr. Adamson also referred to a statement made in the Paper on oil-hardening and air-hardening high-speed steels. The ordinary high-speed steel containing 14 per cent of tungsten could be cooled in air or in oil. In these tests they always used oil.

Mr. Dempster Smith asked if it was any special oil?

Mr. Burley said it was whale oil. The air-hardened steel was a vanadium high-speed steel containing 18 per cent of tungsten and about 1 per cent of vanadium. In hardening those tools, they quenched the extreme end of the nose by placing it in water until it was black, and then dipped the whole tool in oil to quench out finally.

Mr. Simpson (page 851) referred particularly to the question of the hardening of the tools. That was done in the Metallurgical Department of the University by the hardener attached to that Department, and in some cases he (Mr. Burley) was not present at the hardening. The tools tested were all ground and hardened specially for the test; hence there was no question of using old tools. Each tool was tested a number of times, but for each subsequent test the damaged part of the nose of the tool was ground away, so that any part of the metal which was seriously injured by the heating in the prior test was got rid of.

The variations referred to on page 787 were observed amongst the tests made under identical conditions—in other words amongst all the tests that were made on the same or similarly ground tools. Personally he did not think that 15 per cent was a large amount for the maximum variation in tool-testing results when all the possible factors likely to introduce variable conditions were taken into account.

With regard to the question of the colour of the chip, he still thought the statement in the Paper represented the truth. He had seen it stated that the turnings that came off should always be deep blue and if they were not deep blue—apparently no matter

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what kind of steel was being machined—the tool was not working at its maximum efficiency. He personally made the tests, specially to verify this point, and he had not obtained any other results to disprove the conclusions set out in the Paper.

In reply to Mr. Herbert's remarks (page 834), the durability curves were formed from the results of tests made at speeds below what were referred to in the Paper as critical speeds. In Tables 1 and 2 he did not go beyond those speeds in connexion with the durability tests, for the simple reason that under the conditions of the tests they could not produce surfaces which were acceptable as finished surfaces.

With regard to Mr. Saxon's remark re the definition of rake, he knew there was a certain amount of difference of opinion as to what these various angles should be called. He had left out the word "top" because the old bottom rake—he did not know what it was called in Manchester now—was to his mind clearance, and he had simply called the angles on the top, rakes. The front rake was the angle measured in the plane parallel to the length, that is, in the direction of the length, of the tool. The side rake was the angle measured at right angles to the length of the tool. He thought that was pointed out in connexion with one of the figures and one of the Tables given in the Paper (Fig. 86 and Table 14).

With regard to Mr. Bevan's remarks (page 856), concerning the speed-increment test, he knew it was very difficult to relate that to the constant-speed test. He had tried it several times and every time he had failed, because there were too many variables involved in it. To begin with, one could start the speed-increment test at any speed. Some starting speeds of tests were high; he believed as much as 100 feet per minute. He thought that could be called a practical working speed, so that the charge that the speeds employed in this type of test were not practical cutting speeds could hardly be sustained. In the tests on the nose-radius and the tool-section, the intention of the Author was, in the first place, to obtain a depth of cut which would give a life of twenty minutes to each ctool, and the results of those tests had been used because the onditions maintained in those tests were similar to the conditions

maintained in the tests described in the first Paper, dealing with the combined effect of tool section and nose-radius.

Mr. Onions (page 859) was probably right in his reference to the tool with the grooved lip in comparison with one which was ground right back. It was quite possible by so shaping the tool and increasing the section of the tool-nose, to increase its heat-conducting power and thus increase the life of the tool.

With regard to the increase of 500 per cent in the section of the tool, he was surprised to find that there was such a slight increase in the cutting power of the tool when the tool section was increased by that amount, especially when compared with the effect of an increase in the nose-radius of the tool.

Discussion in Birmingham, 1st January 1920.

The Chairman (Sir Gerard A. Muntz, Bart., *Member of Council*) in opening the Meeting, expressed the gratitude of the Birmingham members to Mr. Burley for attending the Meeting. Before calling upon the Author to present his Paper, there were one or two matters concerning the Birmingham district solely that he should be glad to avail himself of this opportunity to mention. The first was, and he made the announcement with the greatest possible pleasure, that there was now every prospect of the Council of the Institution conferring upon Birmingham the distinction of becoming a permanent recognized centre of The Institution in a similar manner to that existing in a few other of the large engineering centres outside London. The members would have their own premises in Birmingham where they might foregather and where Papers could be read and discussions held, and otherwise considerable convenience, not now locally available, be provided. The scheme was not yet entirely sanctioned, but he thought they

(Sir Gerard A. Muntz, Bart.)
might take it as fairly certain that the scheme would go through. He was sure that the making of Birmingham into a recognized centre would be distinctly to the advantage of the membership of The Institution in the city and the surrounding West Midland towns, Coventry especially, at the same time that it would bring the engineers of Birmingham, who never before occupied so proud a distinction throughout the Kingdom for their acknowledged capabilities as they had done since the great War, into more intimate and livelier touch with all the London proceedings. He was proud to testify once again that it was really wonderful what Birmingham and district had accomplished as a munitions centre during the War. Might the distinction which the city had won long remain with it.

The other matter concerning which he wished to say a few words was in relation to the James Watt Memorial in Birmingham. As most of them were doubtless aware, the Council of The Institution had voted £2,000 towards establishing a Memorial Hall in the city on condition that the building should be available for the use of all Scientific Societies in Birmingham, and not merely of the engineers. He thought this a wise provision and he was certain that the vote of the Council would be gratefully received.

The Chairman then called upon Mr. Burley to give a résumé of his Paper.

Mr. Burley then read his Paper in abstract.

The Chairman, in thanking the Author for his Paper, complimented him upon the clearness of his résumé. He (Sir Gerard) would have liked to change the title of the Paper from "Cutting Power of Lathe Turning Tools" to "Lathe Turning Tools and How to Use Them." This was really what the Paper taught. The Paper, however, possessed what he had no hesitation in naming as the distinction of simplicity. The results represented a quite exceptional amount of experimental work. The Author had placed in the hands of machine-tool users results which it was

impossible for them to have ascertained for themselves with anything like equal certainty. He would perhaps not be far out if he pronounced that the bulk of machine-tool users had had some very bitter experiences, many of these obtained in the last five and a half years. Professor Ripper's and Mr. Burley's joint work, now completed, placed within the reach of the machine-tool user of the day a very vital advantage over anything available to those who had to operate machine-tools running at topmost speed and heated production during the War period. Much of the experience which machine-tool manipulators had piled up during the War, very much of it at very considerable expense and pains, would in future be available to those who would take the trouble carefully to study the Paper.

His own experience had been gained rather in the realm of the non-ferrous metals than in association with high-speed and other tool-steel, or with iron and steel generally. But, if he mistook not, the Author's present communication with the preceding one of 1913 would in future become a standard work. He would have been glad if it had been possible to extend the inquiry into the region of the non-ferrous metals, but perhaps that might be a favour which the Sheffield University would confer at some hitherto undecided date. He could assure them that if it did, the University's assistance would be received by non-ferrous metal-workers with enthusiasm. It was a truism that up to the present there had been no standard work upon machine-tool working. After this Paper that time, however, might be fairly said to be passed. It was surprising what difference of opinion existed even among the most experienced and practical engineers regarding machine tool-employment. If any given proposition in this realm of mechanics were submitted to half a dozen engineers or even half a dozen heads of machine-tool working departments, he would guarantee that they would have as many different answers and preferences of modes of working tendered in reply. This was not as it should be. Such confusion certainly did not minister to economy of production, neither to least expensive methods of tool running. The Paper, described in a single sentence, constituted a

(Sir Gerard A. Muntz, Bart.)

set of rules how to use the turning tool, and in the hands of painstaking and practical heads of departments might prove invaluable. He would like to see the Paper passed on to every shop-foreman in the country having to do with machine output upon any large scale, as a guide to the very best methods to employ and to treat the expensive tools that were placed under his jurisdiction. Many of the abundant misfortunes which had been encountered in the workshop in the employment of machine-tools previously should now become a thing of the past. Personally, it was his intention to see that his own chief mechanics and works departmental managers received copies of Mr. Burley's Paper.

Mr. John Fearn, in seconding the vote of thanks, said Mr. Burley was well known by name to many of the Birmingham engineers, and the striking résumé which he had given them that evening of his Paper read in London, would certainly quicken their interest in him. For some years, as most of them were well acquainted, he had been a keen scientific investigator in engineering matters, and he was peculiarly fortunate in having the sympathetic assistance and guidance of Professor Ripper, as shown conspicuously by their co-operating as the Authors of the first part of the Paper which was presented at the end of 1913. For experimental purposes Mr. Burley had at his disposal an unusually complete plant at Sheffield University, of which he had unquestionably made the most, and he might well be congratulated upon being the Author of a Paper upon quite an important subject to machine-tool users which set out the actual results accomplished by the investigations which had been resumed at Sheffield since the War, without too much theorizing attached to it. The subject was one which very closely affected every-day engineering operations in Birmingham and the district, and beyond question the last word had not yet been said upon it. Many people were conducting trials at their own works in much the same direction as the Author had travelled, and these practical experiments would be certain to continue. An immense number of additional machines of the lathe type, American and other, had, he need

scarcely remark, been received in Birmingham during the late period of extreme munitions production, and what everyone was now trying to ascertain was the best use they could make of these greatly extended plants and the most economical results they could secure in the ordinary commercial conduct of trade from their possession.

Mr. P. J. Worsley said the problems dealt with in the Paper were exercising the best thought of many engineering firms just now. The question of cooling was perhaps one of the most interesting points and one upon which it was most difficult to arrive at a wholly satisfactory conclusion. He would like the Author to inform them whether all the experiments were carried out with the same lubricant, because there were, of course, combinations between oils and water, some of which answered better than others.

Mr. Burley said that if Mr. Worsley would refer to the Paper (page 803) he would find that in the first set of tests a soluble-oil compound, diluted with water in the ratio of 3 to 1, was used as the lubricant-coolant; in the second set, compressed air was used as the coolant, both with and without the diluted soluble-oil compound.

Mr. Worsley inquired whether the tools which had been tried were selected from a batch so that their quality might be regarded as a fair average, or were single tools chosen, by which he meant specimens which might perhaps happen to be of exceptional quality? As they all knew, tools varied so much in the matter of cutting endurance that it was quite possible to get very variable results from the same batch, although all had received the same heat-treatment. The safe way to experiment was to repeat the turning trials several times over with many tools from one batch, so as to get a reliable average of the turnings. He would like to know if this was the manner adopted at Sheffield?

Mr. Walter Deakin remarked that the subject of cutting tools

(Mr. Walter Deakin.)
was always attractive to engineers. Among the many interesting facts referred to in the Paper he wished to allude to the experiments with the use of a coolant in cutting processes. There was a difference of opinion on this question, but after the experiments related in the Paper, he considered that the desirability and utility of a coolant were completely demonstrated. He was also interested to note the use of compressed air for the purpose, and quite agreed with the Author that, on the whole, a liquid was more efficient and for some reasons preferable, as, for instance, in cutting on cast-iron the use of compressed air was very objectionable on account of the fine dust which was blown about, and caused injury to the vital parts of machines.

The question of proper tool-angles had been considered before the experiments detailed in the Paper, and much had been done by makers of tool-grinding machines to disseminate that knowledge by means of charts giving the information. The great difficulty was to get the mechanics to put that knowledge into practical every-day use in the shops. In some of the most advanced workshops to attain this end, tool-grinding was a specialized operation and not allowed to be done by the ordinary mechanic; from one point of view this was regrettable, namely, the personal efficiency of the individual mechanic, but from the stand-point of cutting-tool efficiency it was very advantageous. Efficient cutting-tools meant all-round economy and considerable reduction in the coal bill, which was becoming every day a more serious consideration. He endorsed the Chairman's remarks that the Paper constituted a sort of book of rules on the subject, which would be available for reference on the various points dealt with in the careful experiments which the Author had conducted.

Mr. Walter Duckett inquired whether the Author could inform them if the tests revealed any conspicuous advantage in the employment of forged steel for tool manufacture as against rolled steel. It was common knowledge that Sheffield steel-makers professed that the forged material was greatly superior. He would like to know whether the experiments carried out by the Author

were with tools made from forged or rolled bars of high-speed steel, as he was given to understand that a very large number of bars of high-speed steel were forged under the steam-hammer and not rolled. He saw it stated recently that the Ford Motor Car Co. in America had been carrying out experiments on this point, and they claimed 300 or 400 per cent more efficiency from forged steel than from the rolled bar. These experiments related to milling cutters, not lathe tools, and he wondered why there should be a difference between these two types of tool and from the forging point of view. Could the Author oblige them with any information respecting the different makes of high-speed steel? He wanted to ascertain whether the difference claimed by the various Sheffield steel-makers really existed. Personally, he doubted very much the claim set forward. He thought the time had arrived when these matters should be standardized so that consumers might know the exact values of the steels they were buying.

Mr. J. M. Hutt said, with regard to forged tools, that from his own experience, a slotting tool which was simply forged in the ordinary way, allowed to cool down and carefully ground, was quite as good, if not superior, to one that was scientifically hardened. The steel in question was "Novo," and after slotting 200 keyways in "Gear Steel," the tool treated in this way instead of hardening had still retained its sharp corners and cutting edges, and he thought this was due to the influence of hammering during forging. He had found the same results from turning tools, as his firm's turners preferred a "Novo" tool direct from the smithy, and carefully ground, without being hardened.

Dr. H. G. Wigg inquired if the Author could give some information with regard to the method of the failure of the tools. Was it due to an alteration in the structure of the steel at the cutting edge or near it, or was it simply the result of wear? He did not know if this point had been looked into. He would also like to know whether the Author had formed any views as to the

(Dr. H. G. Wigg.)
reason of the differences noted with variation in radius of the nose of the tools.

The Author seemed to think that the height of the tool was of very little importance. This was certainly contrary to his own experience. His conviction was that in roughing it was a distinct advantage to have the tool above the centre. In this position the greater top-rake enabled the cuttings to come away in a large diameter coil. Lowering the position of a tool made the cuttings come off in a coil of smaller diameter; when below the centre the roughing tool either cut a coil of very small diameter or else the chips came away in broken pieces, requiring, apparently, a good deal more power. He suggested that a heat-balance might be got out showing how the horse-power consumed at the nose of the tool was distributed in heat units between the job, the turnings, the tool, the coolant and the surrounding air. It would be very interesting to get an approximate idea of the temperature of the nose of the tool at the time of breakdown, that is, at the end of its "life," when it ceased to give satisfactory results. Probably no simple method of measurement of temperature would be possible, but if certain limits of temperature were reached, the microstructure of the metal might show changes as compared with a tool that had run a shorter period of time.

There were apparently two methods of failure: the first by wear and the second by change in the steel due to high temperature. These methods were, no doubt, closely related, and probably the wear took place much more quickly as the temperature increased. If it were possible to use a highly refrigerated coolant, probably the life of the tool would be increased. Conditions might conceivably arise when it would be more economical to keep the coolant at a low temperature than to change the tool.

The Author gave very few particulars of the tool-steels used. If he could give composition and details, including temperatures and times taken in the process of hardening, it would add to the value of his Paper.

Mr. W. H. Bailey, who said he had had ten years' experience

in the use of cutting tools fixed above the centre, asked Mr. Burley if, following up his tests, he had any rule respecting the height of tool above the centre. He had himself found that raising the tool $\frac{1}{8}$ inch per inch diameter of the work was a very good rule, and easy to remember. He had experimented on a piece of work 3 feet 9 inches diameter with a formed tool 5 inches wide set at 6 inches above the centre. This produced a very good curly chip without vibration or chatter, which one would expect to get on a piece of work of this diameter. He showed to the Meeting a sample cutting 5 inches wide taken by himself seven years ago with the formed tool mentioned. He knew well enough that the opinion he had expressed was hardly orthodox. The majority of foremen had of course an objection to placing the tool above the centre, but he was persuaded that it was the right thing to do. No matter what the diameter of the work in hand, it was without doubt an advantage to act as he had described. He should like to emphasize that, in addition to increasing the cutting effect, it economized the power absorbed. Tools used in this manner required no forging; it was only necessary to give sufficient clearance angle, no top-rake being required. At the same time the tool lost nothing in strength at the point, owing to the slightly increased angle required for clearance. He expressed his indebtedness to the Author for having given him the opportunity of stating his experience with cutting tools fixed above the centre. This was the first time he had had the privilege of doing so, or of listening to any discussion directly bearing on the subject.

Mr. W. A. BINKS said that every mechanic had his own ideas as to what the tool-angles should be, and it was most difficult in the workshop to get any agreement upon this point; the result of the experiments set down in figures was most interesting. He took exception to the Author's always arranging, when dealing with the top angle, for the cutting edge of the tool to be horizontal. In many cases in workshop practice it was not usual to so arrange the shape of the tool, and the men would not trouble to set the tools in this way. He wondered whether the Author had

(Mr. W. A. Binks.)

experimented with a different combination of angles to that described—for example—with an arrangement which would make the cutting edge (1) higher at the point than at the back; and (2) lower at the point than at the back. It would be interesting to ascertain what relation either of these two arrangements of angles made to the life of the tool and work done. He thought the Paper would be more valuable if further details were available, to show that as far as possible the personal element and chance were eliminated; for instance, the forging of turning tools in comparison with those that were not forged. So much depended upon the human element in forging and in hardening that to obtain satisfactory results, quite a large number of experiments should be made and an analysis taken. In no other way could the possibility of error be eliminated.

Concerning coolants, he would like to know if the Author employed a variety of liquids, such as different varieties of oils, etc., or whether he used one coolant throughout? This question was a source of controversy in some shops.

Mr. GEORGE W. BURLEY, replying to the discussion, thanked the speakers for the fair way in which they had discussed the Paper. Dealing first with Mr. Bink's criticism, he said that no result given in the Paper was the issue of a single test, since in every case the tool was tested either three or four times, whilst many of the results were the averages of tests made on a number of tools. The most important case of the latter type was the one referred to on page 794 of the Paper, this being one in which a conclusion regarding the comparative cutting power of forged turning tools and unforged tools was drawn from the results of an investigation in which nearly 1,000 individual tests were made. This example was exceptional he recognized, but it served to illustrate his meaning. One thousand tests were made on 332 tools of similar shapes under identical conditions, and an analysis of the results was afterwards taken. The tools in question were made specially during the War from steel bars made by seven or eight different tool-steel manufacturers to certain specifications of the Ministry of Munitions. Each bar was

cut up into as many tools as it would accommodate, and one-half of these were forged and ground, whilst the other half were simply ground to the same shape without any initial forging. All the tools were tested on the same kind of material, which was a fairly hard bar, under identical conditions, and the results of these tests averaged.

Mr. Binks, with a Coventry experience, had called attention to what he was pleased to call the danger of the human element in forging and hardening, and he had suggested that this might minimize the accuracy of the results obtained. He, the Author, thought after what he had just said, that Mr. Binks would agree with him that, in the experiments made at Sheffield, everything possible had been done to minimize any error arising from the "human element" so called. The workman who forged the tools was a good and reliable smith, entirely unprejudiced, and without any knowledge as to what the tools were wanted for, or the differences between the various steels.

With regard to tool hardening, upon which questions had been asked, the tools were not separated or hardened in any particular order, but they were simply all mixed up, and the hardening of the forged and unforged tools proceeded together. This was done to eliminate the influence of the personal or human element in this operation, and in this matter the practice of the University in 1919 was only a repetition of that observed in 1913.

Respecting coolants or lubricants, only one kind was used, namely, a composition of soluble oil and water in the ratio of 3 to 1. As it was necessary to confine the experiments within certain limits to allow of their being completed at all, he did not try different kinds of cooling media. He recognized, of course, that the question of coolant experiments was a very big matter and of considerable importance, and it was one that the University would probably deal with later on. But Birmingham would recognize that Sheffield could not do everything at once, and there were one or two other researches afoot which were rather more urgent.

Concerning Mr. Duckett's inquiries (page 868) whether forged

(Mr. George W. Burley.)
or rolled bars were the more superior as a tool material, and whether the large differences in the prices of various high-speed steels were justified, he was sorry not to be able to render much help. He was an engineer, not a metallurgist, but he doubted very much whether there was any "best tool steel" in the world. He thought he would be right in saying that an 18 per cent tungsten steel with 1 per cent of vanadium in it was better than a 14 per cent tungsten steel without vanadium. The carbon-tool steel supplied for the experiments, he believed, was made from rolled bars, but the bulk of the high-speed tool-steel was made from hammered bars. He believed that the Sheffield steel-makers found it rather difficult, if not impossible, to roll high-speed steel. He quite agreed that the treatment received by the steel bar before it passed into the machine shop was an important factor in determining its utility and cutting qualities, and there might be a real difference between tools of the same composition made from rolled bars and forged bars. One of the main influences which incited his investigations in this matter was the widespread opinion in Sheffield and district that mechanical work, either in the shape of forging or hammering, put upon steel intended for cutting tools of the class of scissors and such like light tools of Sheffield make, improved the cutting quality and finish of the steel, and he was anxious to ascertain if the same rule applied to the class of larger and heavier metal cutting tools like those used in lathes and other machine tools.

Inquiry had been made from him by Dr. Wigg (page 869) concerning the nature of the failure of high-speed steel tools of the lathe type. In reply he pointed out that there was not quite unanimity of opinion amongst those who had studied the matter, probably because it was very likely that there were several slightly different ways in which high-speed steel tools did break down. Generally, however, it could be said that when such a tool was put to work with a cut of reasonable proportions, the extreme cutting edge of the tool acted as a sort of scraper, and the cutting action was probably of the nature of a shearing action. The major part of the heat which was set up was simply the heat generated by the mechanical operation of shearing, and the greater part of this passed

into the turning and not into the work. Without possessing an approximate heat-balance, he could not make a more exact statement regarding the relative amounts of heat taken up by the turning and the work. Such a balance could be made for any particular case, but whether it would be of much use he was not convinced, owing to the variety of conditions met with in practice. In any case, however, as the turning moved over the lip surface of the tool some of the heat contained in it passed to the tool, and this amount of heat was supplemented by that resulting in the overcoming of the frictional resistance between the turning and the tool. Part of the total amount of heat communicated to the tool travelled towards the cutting edge of the tool and the rest in the opposite direction towards the shank. This latter amount of heat was of account inasmuch as it determined the amount of heat which passed into the very close space at the extreme tip of the tool, and the greater the amount of heat that passed in that direction the sooner the tool broke down. It would be quite wrong, however, to imagine that the cutting edge of the tool was actually fuzed. It was not so. A temperature above 1,300° C. (2,372° F.) was required to fuze the edge of a high-speed tool, but he had never seen the body of the nose of a tool such as he had described which would be much above 800° C. (1,472° F.), and the temperature of the tip of the tool was probably less than this. If the turning pressed on the surface of the tool sufficiently to wear a groove in it, the groove gradually widened out in each direction, and the rate at which it widened out depended upon the temperature of the tool. At the beginning of the life of a tool the rate of grooving was not very important, but ultimately a point was reached when the pressure on the extreme edge of the tool was sufficient to produce a shearing effect on the nose, and under such circumstance the extreme edge of the tool was actually sheared off, and the piece so removed could in many cases be actually picked out from the end of the cut on the test-bar or work-piece. He had himself done it repeatedly.

Respecting the question of the height of the cutting edge of the roughing tool with respect to the centre as mentioned

(Mr. George W. Burley.)
by Mr. Hutt, and to which Mr. Bailey had also referred, his experiments were simply conducted to ascertain what effect the position of the tool had upon the life of the cutting edge of the tool. The question of "chatter" had been raised at the Manchester Meeting, but the scope of the present investigation excluded it. At some future time the subject might be taken up. He fully realized its importance in the machine shops of the modern engineering works.

Mr. Binks had inquired as to the arrangement of the side and front rake so as to make the cutting edge of the tool horizontal. As a matter of fact that was the condition originally adopted a number of years ago, and in the latest investigations it had not been changed because no points calling for such a change had been dealt with. No experiments had been attempted with tools ground so that the cutting edges sloped downwards or upwards towards the point. He could not, therefore, help Mr. Binks to any safe conclusion on this matter. But, in their researches during the War, the University found that a tool with a cutting edge sloping downwards did better work on alloy steels than one with a horizontal edge, and also lasted much longer.

Discussion in Sheffield, 5th January 1920.

The CHAIRMAN (Mr. H. E. Yerbury, *Member*) said they were fortunate in having before them a Paper of special interest to engineers, and one which had been considered worthy of being read in London, Manchester, and Birmingham. It was a continuation of a Paper read in 1913 by Dr. Ripper and the present Author, which he (the Chairman) thought, taken as a whole with the discussion, might be rightly regarded as a classic treatise on the

subject. He had great pleasure in asking Mr. Burley to read his Paper.

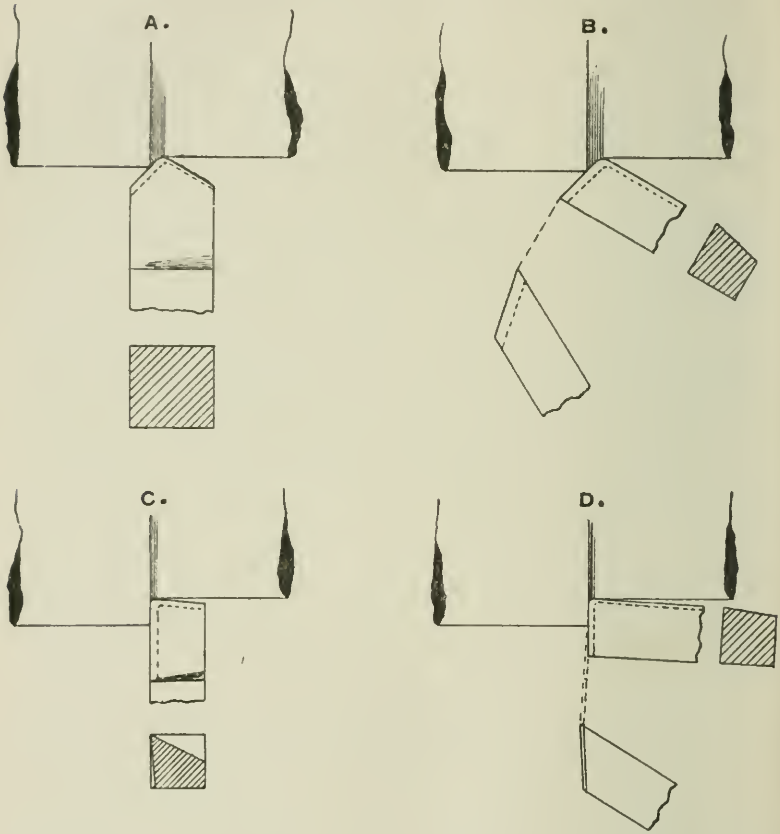
Mr. BURLEY then gave a summary of his Paper, and at the conclusion—

The CHAIRMAN said he felt sure there were many engineers present whose observations, and perhaps criticisms, would be welcomed. It appeared to him to be an excellent policy, that of continuing a Paper when additional experimental research work had been conducted. They all knew that whatever machine was designed or tool manufactured, it was the brain behind it which made it work at its maximum efficiency. They had that night another happy instance of some of the best brains of the Sheffield University brought to bear on the practical work of lathe and machine tools, and it was, he thought, very gratifying to know that work conducted at the University might be so directly associated with lathe and other work and the results made known throughout The Institution. Any information which tended to increase efficiency and output and lower manufacturing costs, and thereby give greater ability to compete in the world's markets should, he thought, be welcomed by all engineers. The Author, he noticed, used electrical instruments for the measurement of power, and he thought one must admit that, since the electric drive had been adopted, great economies had been effected and far greater accuracy obtained in the measurement of power taken during any specific operation. The Author had set out an admirable summary of his conclusions and each paragraph should evoke some discussion.

Dr. F. ROGERS said that it would be difficult to avoid the metallurgical aspect in a discussion on tools in Sheffield. One of the principal features in the Paper had been the question of the angles of cutting tools. In one respect he thought that some of the angles had not received all the attention amongst engineers that they deserved. As far as the angles were concerned a tool consisted essentially of its nose. The form of nose or cutting edge having

been decided upon, the shank of the tool could be decided next and to a great extent independently. Taking a roughing tool, shown at "A" in the sketch, Fig. 96, the shank of the tool was at right

Fig. 96.—*Types of Tools made from High-Speed Steel.*



angles to the axis of the job; at "B," the nose of the tool was of exactly the same form, but the shank of the tool was inclined to the axis, and was simply a prolongation of the nose. The advantages of that form "B" were that it could be produced from steel rolled to a suitable section, for example, that shown in

"B," with three sides rectangular and one side bevelled. The cutting edge of that tool was made or maintained merely by grinding one angle and the nose-radius. Another example was that shown at "A," namely, the side tool, to which reference had been made by Mr. Vernon in the discussion in London. That tool could be rolled to the section shown in "C," two of the edges being at right angles, and two bevelled.

A similar result could be got which was applicable to many jobs, and presented certain advantages, by the tool of the type shown in "D," which was made from bar rolled to rectangular section, except one side bevelled. Either of those tools was maintained by grinding one angle and nose-radius only. In the design of tool-holders those methods had been recognized to a certain extent, but they were capable of much extended application. The argument that in that form those tools did not lend themselves freely to use on, say, common English engine lathes, was, to say the least, a very poor one, and so far as repetition work was concerned that argument ought not to be allowed to obtain at all. From the mechanical point of view, therefore, the advantages of designing tools on that principle were evident. Metallurgically there was also an important advantage; that was particularly clear in comparison of the forms "C" and "D." It ought to be remembered that even in the very finest steel there was a slight "grain" running in the longitudinal direction, which meant that the steel tended to be slightly weaker on longitudinal planes than on transverse ones. Consequently the tool of the form "C," whose edge was parallel to the imperfections, was being stressed in the manner it was least able to resist, whilst the tool in the form "D," whose edge ran across the elongated imperfections, was being stressed in the most favourable manner. He had, from time to time, to investigate failures of tools which were traceable to that particular cause. Doubtless many of those present had encountered instances of trouble from the longitudinal splitting of tools near the cutting edge. More attention was, however, gradually being paid to forming cutters with the "grain" in the most favourable direction possible. The tools which he showed, illustrative of the

(Dr. F. Rogers.)
forms suggested, happened to be made from a high-speed steel in which molybdenum was the principal alloy and tungsten absent, a steel of which hundreds of tons per annum were being made and sold in Sheffield.

Mr. F. KENNERLEY PRESTON said he was glad to know of the good work which was being carried on in Sheffield University. He noticed that the Author mentioned that in a previous discussion someone had raised slight objection to the accuracy of the figures of one test made. He (the speaker) happened to come under the influence of Professor Ripper a considerable number of years ago and had made innumerable experiments with him. Several times he (Mr. Preston) thought he had got accuracy, but no, "Do it again," Professor Ripper would say. He was therefore one of those present that evening to accept absolutely the accuracy of those figures, seeing that Mr. Burley was connected with Professor Ripper, and he was sure that every result and every figure in the Paper had been well verified.

The Paper was so replete with facts that really there did not appear to be much to discuss, unless one had put into actual practice some of the tools with the various angles and applied them oneself, and he had not had a chance of doing that. There was, however, one point that occurred to him, namely, that of coolants. They all remembered the old shops where the oil was poured on, not nicely pumped as at present. The tool steel, generally, was not good; angles very inefficient; and when the fumes came off, the men were nearly poisoned. He noticed that the Author had suggested air cooling, and it struck him there was much in its favour if the cost of compressing the air and cooling it were small; if they could bring in so many thousand cubic feet of compressed air in a certain time into the shops and do useful work with the same, inasmuch as using it as a coolant and lubricant in this particular sense they were doing very good work, they were improving the health of the people, keeping a nice buoyant atmosphere in the shops, and if the cost was not prohibitive that method ought to be investigated a little further. The cooling

effect of the compressed air might be made easy by using the ordinary circulating water or the ordinary feed-water of the boilers, or in other cases even drinking water, to take away the heat-units in the small compressor. A small electrical compressor near the turning shop might not be a very serious item of expense as compared with the cost of oil. It struck him as rather a good idea if they could get air cooling and of course water cooling and an oil cooling mixture finely sprayed on, but if they could get air cooling alone, he thought it would be a very good advance indeed.

He noticed that the position of the tool, in relation to the centre (page 789), was very interesting to one who had left turning alone for some years, because it bore out exactly what one had been told in his apprentice days, exactly where to put the tool-nose relative to the axis of the work to be done.

Colonel R. E. B. Crompton, C.B., R.E., said that, having been present and having already spoken at the London Discussion on the Paper, he had come to Sheffield expressly to hear what the Sheffield steel people had to say on the part that the latest up-to-date high-speed steels would play in the improvement of tools used for cutting metals. To avoid repeating what he had said in London, he would confine his remarks to pointing out that the Sheffield speakers did not appear to realize that the extraordinary qualities claimed for the super high-speed steels—particularly those containing molybdenum with cobalt — would greatly influence this question by enabling research on the form of cutting tools to take a step forward, and which in his opinion might, and very probably would, revolutionize our present ideas.

So far his personal observations tended to show that these new steels presented extraordinary qualities in two respects: that of great hardness at temperatures of 500° to 600° C. (932° to 1,112° F.), commonly called red hardness, and great strength at this temperature to resist the forces which tended to break away the cutting edge at the point where it became weakened by the groove formed on its upper surface by the friction of the chips passing over it. These two qualities would enable lathemen to

reduce the included cutting angle and thus to reduce the torque required to split away the chip, and at the same time to reduce the heat generated at or near the point. Again, he thought that they ought now to encourage steel manufacturers to send out lathe and similar cutting tools ready hardened and tempered throughout their length, so that the user need only grind them on one face, or at most on two faces.

The Institution was doing great service to the Engineering Industry by having formed a Committee to deal with this question of the improvements of our knowledge of cutting tools, and he called upon the Sheffield engineers to give their help and to work with that Committee. All who had special knowledge should pool their ideas by communicating them to that Committee and in so doing would enable Sheffield and England to hold its own in an honourable rivalry with American or Continental Engineers and Metallurgists. He, personally, as the Secretary of International Electrotechnical Standardization, had much favourable experience of team work which had so greatly helped forward our knowledge of Electrical Engineering, and he hoped that we should do the same with this particular problem of Mechanical Engineering.

Mr. A. BAYLISS said the Paper carried his mind back to some years ago, when he had the privilege of hearing Mr. Taylor's Paper read. Since then he had been able to make many experiments, both on the lines of Taylor and of others who had been closely working at the subject, in actual practice. As the subject was such a very large one, he would only touch on two points, which did not appear to be in the Paper—first the forging, and secondly the grinding. It had always been his experience—and the experience in the shop, where they had made some thousands of grosses of lathe tools—that the shape of the tool, or rather the section of the tool steel, should be one and a half times as deep as it was wide. It should be, say, $\frac{3}{4}$ inch by $\frac{1}{2}$ inch, and a square steel should not be used. Also, the proper length should be used for these lathe tools. In passing round the shop that day he saw a workman trying to use a bit of tool-steel about three or four inches long in a

tool-box. The chatter, of course, one easily understood. As to the shape of the tool itself, it should be so forged that the dressing that was done to it, when it required to be dressed, should be of the simplest kind, the forging naturally costing very much more than the grinding. The forging of an ordinary tool at the present day cost about $7\frac{1}{2}d.$, while the grinding would cost only about $1d.$ As to the heating during the forging, one had often stood near a smithy and watched the smiths at work—how they would plunge a steel backwards and forwards into the fire; but his experience had been that a tool which had only been heated twice in its manufacture gave the best results. They had often read in books, "Constantly heat a thing; don't work it too cold," and so on, but he found that the two-heat system worked out the best: the forging should soak gradually until about 800° to 830° C. (1,472° to 1,526° F.), and then to a good yellow.

A large number of cracks were constantly occurring in lathe-tools. This was due first of all, probably, to pipes in the steel, or it might be due to shocking the steel while it was cold. It was no uncommon thing to watch a smith and his drummer put the cold set across, and then give it a sudden blow with the hammer across the hole and jar it the whole way up. The best method, he had found, in cutting the tools, was to cut them hot, or if necessary to saw them off previously into the required lengths, putting three or four pieces in a gang cutting saw at a time; then cut them off in eighteens or twenty-fours, and let them drop down in the ordinary way.

As to grinding, more tools were spoiled from overheating whilst they were being ground than from any other cause that he knew of. The grinder would burn more than the blacksmith would burn for them, and hence such bad results were obtained. Grinding wet, he had found, gave the best results. There should be a throw of water upon the stone, or upon the tool, of about three gallons per minute. The auto-grinder, of course, was the best. The best wheels he had found for grinding lathe-tools were from 24 to 30 grit.

With regard to cutting speeds, these were governed, first of all,

(Mr. A. Bayliss.)
by the hardness of the material to be turned; secondly, by the steel they were made of; thirdly, by the feed and the depth of the cut; and lastly, by the lubricant that was used. He had found that the best cutting speeds, to run, were: for ordinary machine steel, 45 to 60 feet per minute; for cast-iron, 40 to 50; for annealed tool steel, 25 to 35; for ordinary yellow brass, 145 to 185; and for hard bronze, 50 to 70. These had been his experiences, covering some lengthy period, and he trusted they would add a word or two to the Paper, which had been so valuable to them.

Mr. J. H. BARBER said he remembered being associated with Mr. Burley some years ago in some lathe-tool tests, and he would like to add a tribute to the very careful nature of the work he had carried on and the thorough nature of the results he had obtained. One who had done some of those tests could appreciate the amount of careful work that was required to get those results, and he thought they really ought to congratulate Mr. Burley and Dr. Ripper for the work that had been carried out and the nature of the results that they had obtained. There were so many variables that, in order to arrive at something like a reasonable result, they had to carry out very many trials, and to reiterate constantly until they had reached some reasonable basis for deduction.

It had been remarked in the discussion that the finishing on large shafts was done with a broad feed. Whether they could let that enter into the question he did not know, but that, of course, was the practice, and probably the best practice. It was rather a pity, although perhaps it was incidental to the job, that the tests were all carried out on large diameter shafts, because most of the turning, he supposed, was on shafts which were very much smaller. With regard to finishing, of course on small shafts this was got with a water finish, which was depended upon very much in turret-lathe work and so on, without anything on top of it.

With regard to steels, some of them had been experimenting for a good many years, and he thought the main opinion in Sheffield was that what they heard of these new steels was similar to what they had heard before; and, while they did not wish to

detract from the value of anything new, they would like to have some facts and figures which would tend to settle the matter before it was taken for granted that this new steel was going to surpass all other steel.

Mr. J. FERDINAND KAYSER said he thought the results obtained by the Author were of a very modest nature. For instance, he recorded in Table 5c (page 775) a 14 per cent tungsten high-speed tool, taking a $\frac{1}{8}$-inch cut, on a $\frac{1}{12}$-inch feed, which, starting at 30 feet per minute, failed in 16 minutes 40 seconds. He (the speaker) supposed that would be at a speed of about 47 feet per minute. Under the conditions of the test, such a performance, which was the best of several, was very poor, and it appeared as if there must have been something seriously wrong with the hardening of the steel. Curves were also given, showing the relative durability of a carbon steel and a 14 per cent tungsten steel. It was either a very good carbon-steel or a very inferior tungsten-steel, because the curves were far too close together. He had always found a much greater difference between two such steels. On page 776 there was a formula connecting associated speed with various other variables. Applying this formula, the associated speed became zero when the steel to be turned gave a tensile strength of 67 tons per square inch in one case and 65 tons in the other, yet a 65-ton steel was quite a usual thing to meet in the workshop.

Regarding the question of forging, this was essentially a heat-treatment operation, and he thought it was always as well to omit heat-treatment operations if possible. Forging was generally quite unnecessary; it was merely a matter of getting the material in the right form. It was possible to take a high-speed cast-bar of equal section to a forged tool, and, by annealing that cast-bar and putting it through the heat-treatment process, they obtained the same durability as they would from a bar made from forged material. One of the speakers had referred to a forging heat of about 800° C. to 830° C. (1,472° F. to 1,526° F.), and also mentioned that forging should be completed in two heats. It would be useless endeavouring to forge high-speed steel from such temperatures and

(Mr. J. Ferdinand Kayser.)
even carbon-tool steel was generally forged from nearer 900° C. to 950° C. (1,652° F. to 1,742° F.)

As soon as he became associated with high-speed steel tests, he was struck by the fact that they had nothing such as the structural engineer had in the way of tests. He (the speaker) looked into that question very carefully, and finally he devised a machine for determining Brinell hardness of hardened steels at temperatures from atmospheric up to about 800° C. to 900° C. (page 831). Using that machine he had obtained Brinell hardness curves for several different types of high-speed steel at various temperatures up to about 800° C. After comparing those Brinell curves with the previously determined cutting efficiencies of the different steels, he (the speaker) affirmed that Brinell hardness was a criterion of cutting efficiency, but it was useless to compare the hardness of a tool at atmospheric temperature, when, under working conditions, such a tool was habitually at a temperature of about, say, 300° C. to 400° C. (572° F. to 752° F.).

That brought them to the question of what temperature a tool-nose attained during cutting operations. Many people affirmed that they had seen a cutting tool turning with its cutting edge red hot; he absolutely denied the fact that any high-speed steel whatsoever could cut at all when the cutting edge was red hot. It was quite true that behind the cutting edge there was a red glow, but the cutting edge, which was in close, intimate contact with the cold revolving bar, could not be red hot, for the amount of friction at the cutting edge was not great, as could be seen by an examination of any tools that had failed. Just recently, he had had a chat with Mr. Burley, who showed him some cutting edges which had been torn off and buried in the bar at the moment of failure. Mr. Burley very kindly chipped out one of these edges and he (the speaker) examined it under the microscope. The original grinding marks were still visible and he thought that in that particular case failure had occurred in the following manner:—The cutting edge had remained comparatively cold and hence hard, but back of the cutting edge where the cooling effect of the revolving bar was not so pronounced,

a much hotter zone had developed, until ultimately the cutting edge had been torn out of this hotter and hence weaker zone. An 18 per cent tungsten steel plus 1 per cent vanadium, with carbon, usually gave a Brinell hardness of about 420 at 609° C., yet a tool made from that steel would easily cut a nickel-chrome steel with a Brinell hardness of about 300. He thought it was impossible that it could have cut such a bar if the cutting edge had been at 600° C. (1,112° F.). At 750° C. (1,382° F.), which was a figure frequently mentioned as the temperature of the cutting edge of a high-speed tool during turning, the Brinell hardness of the aforementioned steel was only 310. One of the chief cooling mediums during cutting operations, he considered, was the bar itself, which was cold, and cooled the cutting edge. The next and most important cooling factor was the tool itself. The mass of the tool took away the heat from the cutting edge, and was one of the chief cooling agents. Of course, if that could be helped by means of a coolant so much the better.

With reference to cooling cutting tools, there was one extreme experiment which he had carried out several times, and which, while quite impracticable as a workshop operation, gave a very interesting result. He placed several tools in liquid air and then put them to work. Those tools failed almost right away, and even when allowed to regain atmospheric temperatures it was found that the cutting efficiency had been seriously impaired.

The temperature to which a tool should be cooled before it was put on the lathe was a very important factor which did not appear to have been considered by mechanical engineers. It was essential, that after hardening, a tool should be allowed to cool to atmospheric temperature before being put to work. For while a high-speed turning tool would cut quite satisfactorily when heated to, say, 200° C. (392° F.), if only allowed to cool from the hardening heat down to that temperature and then put to work, its cutting efficiency had been found to be extremely low. [*See* also page 831.]

Dr. William Ripper, C.H., said he had not intended to

intervene that night, and he had no doubt Mr. Burley would deal with the many points that had been raised. He might say that their original Paper was presented, as Mr. Burley had explained, to try and get to the bottom of a statement that the slower they worked a tool the shorter its duration of life, and, on occasion, that the faster they worked a tool the longer its duration of life. That seemed to him such a heresy that it was worth investigating, particularly in a centre like Sheffield, which had so much to do with the manufacture of tool-steels. The first Paper was prepared, therefore, just to deal with that particular point, and the various curves that they made were done to try and express the law which they obtained over a great range of speeds, without concerning themselves whether the speeds were the maximum speeds possible in works or not.

During the discussion of the first Paper a number of questions were asked, and another Paper was promised dealing with the questions raised. This second Paper was the result of that promise. Mr. Herbert had said that if his statements had only had the effect of getting these Papers contributed, they had served a useful purpose. If the Papers that had been read had served no other useful purpose than that of provoking the interesting discussions they had listened to, he was quite sure they had been worth while. At any rate he had listened with great interest to the Paper which Mr. Burley had read, and to the discussion that had taken place, and he thought that the many points which had been raised would usefully form the subject of still further investigation.

Mr. C. G. Carlisle said he rose because of the remarks of Mr. Kayser (page 885). He had lately been working on high-speed cutting tests and that gentleman's statement that red hardness was not obtained rather struck him as peculiar. He tested a tool that gave him a life of 145 minutes, running at 45 feet per minute, on a hard bar of 0·70 per cent carbon, 0·77 per cent manganese normalized (not annealed), with a Brinell hardness of 255. As time went on the tool tempered itself. The blue tempering colour (300° C.) was about $1\frac{1}{2}$ inch from the tool-nose. The whole lathe became very

warm. The bar at this stage was about 8 inches in diameter, 5 feet long, and was also distinctly warm. After one hundred minutes had elapsed, the tool and the chip began to show redness, which continued till exhaustion occurred. The temperature must have been somewhere about 600° or 650° C. (1,112° or 1,202° F.), a dull redness which was distinctly visible in ordinary daylight.

Mr. Kayser asked if it was at the cutting edge.

Mr. Carlisle replied that it was.

Mr. Kayser further inquired if Mr. Carlisle saw the edge.

Mr. Carlisle said he did not because at that time it was worn away. When the bar was taken out, a well-defined cavity was cut out quite square. It was quite different to any other tool he had ever seen. It must have been at the temperature he had mentioned because the temperature about $1\frac{1}{2}$ inch behind the nose must have been over 400° C. (752° F.) as it was well beyond the grey at the finish of the test. Therefore it must have been somewhere in the region of 600° C. at the tool-nose, the tool in question being heavy in section $1\frac{1}{4}$ inch square.

They had had a speech from Colonel Crompton in which the metallurgists were put on their mettle. In connexion with that, he would like to show the curves, Fig. 97. The test which he had just described was made from an electric high-speed steel of the 18 per cent tungsten type hardened in water. He found it was capable of being hardened in water without any serious danger of cracking. Hardening in air gave him slightly lower results at 55 and 45 feet (exactly the same at 50 feet) than the crucible type of the same analysis, but the water hardening gave distinctly superior results at all speeds, especially at 45 feet per minute. The cutting angle was 30°, the included angle was 70°, and front clearance was 5°. This small research was carried through to find the relation between speed and endurance. He had not been satisfied with the ordinary test that manufacturers usually adopted

(Mr. C. G. Carlisle.)
of running at high speeds and allowing]it to stop there, he wanted to find out what happened at lower speeds, but yet well over ordinary shop practice.

The only value about the curve which he produced was that he

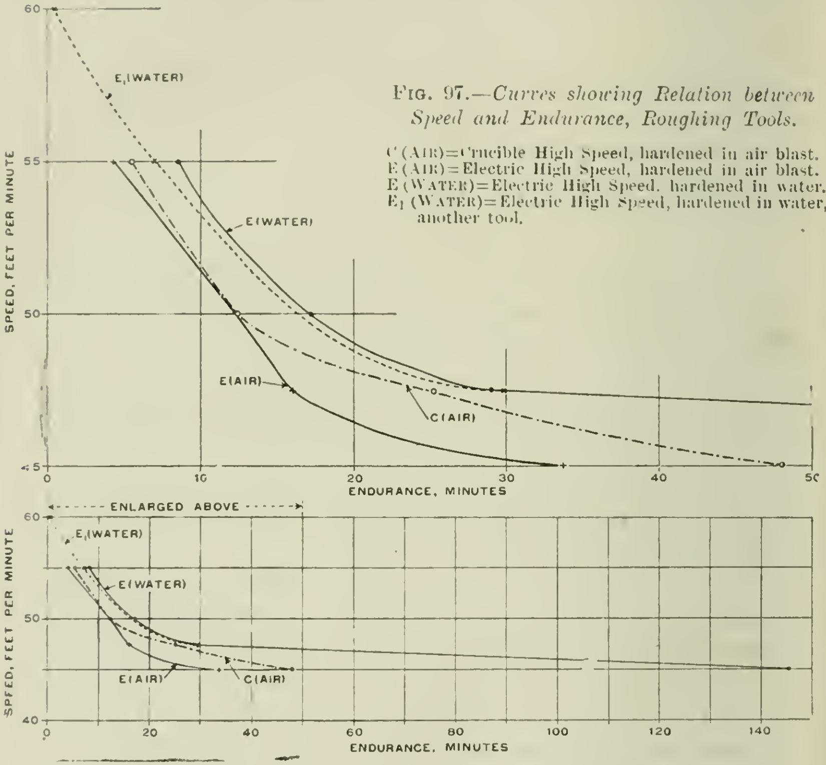


FIG. 97.—*Curves showing Relation between Speed and Endurance, Roughing Tools.*

C (AIR)=Crucible High Speed, hardened in air blast.
E (AIR)=Electric High Speed, hardened in air blast.
E (WATER)=Electric High Speed, hardened in water.
E_1 (WATER)=Electric High Speed, hardened in water, another tool.

would be able to use it in future as a standard, and instead of using 65 feet or 55 feet as a speed to test the quality of the steel, he would probably use lower speeds as greater differences could be found in the steel by so doing.

He must commend the Author of this Paper and the Authors of the previous Paper on the faith reposed in the three variables: the homogeneity of the test-bar, of the tool-steel and the hardening

operation. These were three variables even in the hands of the best experts, and seeing that they had given such wonderful results, he must compliment them for their faith in these variables, which they almost ruled out as constants. That was rather a recommendation for the products that had been used as test-bars and for the tool-steel that they had used.

Mr. G. W. BURLEY, in reply, first thanked the speakers for the fair manner in which they had discussed the Paper, but said that as the time was rather late, he would only refer to one or two of the more important points which had been raised, leaving the others for inclusion in the written reply to the discussion. He thought that the difference between Sheffield University and Colonel Crompton was largely due to a difference in point of view, and that Colonel Crompton's case was partly met by the first Paper. The Colonel pointed out that the speeds which were referred to in the present Paper were very low, but as he (the Author) understood the case, Colonel Crompton's cuts would be more in the nature of roughing cuts than of finishing cuts, such as were dealt with in the first two sections of the present Paper.

Reference had been made to the fact that the tool shapes were described, or rather defined, in a certain way, which was regarded as being peculiar, namely, by referring to the top angles. He (the Author) understood that "top rake" was a term that had been in use for a good number of years, and in shaping tools upon certain universal tool grinders, for instance, what they required were the top angles and not the tool angle. But in any case it was a simple matter to obtain the one from the other. The sum of the clearance angle, the tool angle, and the top rake, was always equal to 90°.

In regard to the part of the work dealing with the position of the cutting edge of the tool, he would like to explain that that work was done simply because the knowledge came to them that it was the practice of some people, whose business it was to test comparatively high-speed turning tools, to place the tools so that the cutting edges or points were a little above the centres of the

(Mr. G. W. Burley.)
lathe. It had been the practice at the University, and still was, to place the cutting point or edge on the centres, but they, at the University, wanted to know whether there was any advantage in adopting the practice of other people. This was all the significance of that section of the Paper, and it was included because it was thought to be of scientific interest.

In regard to Mr. Carlisle's remark with reference to their unbounded faith in the constancy of the variables met in lathe-tool testing, namely, the test-bar, the tool-steel, and the hardening of the tools, it should be pointed out in the first place that all the test-bars used in the tests covered by the Paper were specially made, though he did not mean by that that they assumed the bars to be absolutely uniform, but he thought that the lack of uniformity was very small in this case. At the same time, however, they averaged out the variations by making the tests under otherwise identical conditions on different parts of the bar, and not confining all the tests with one tool to one part of the bar. In their case that was possible, because many of the tests did not run from one end of the bar to the other. The tool-steels that were used were ordinary commercial steels, purchased in the ordinary way and not made specially for these tests, whilst the methods of hardening them were the most scientific methods that they had in the Engineering and Metallurgical Departments of the University, including electric-bath heating for the high-speed steel tools.

The Chairman said those present had already shown, by their applause, how much they appreciated the Paper, but he felt it would ill become them as engineers to disperse without formally moving a vote of thanks, and he asked Colonel Crompton to undertake that duty.

Colonel R. E. B. Crompton, C.B., R.E., said it was a great honour and pleasure to him, as a stranger—although he was a Yorkshireman—to be called upon to do this. He heard that in Sheffield they were a hard lot, and that they were tough, but he

believed they were also intelligent, and he was pleased to come among them that evening, and to find that, both in the Chairman and in the Author of the Paper, they had on the platform people worthy of Sheffield. He hoped that in the discussion he had said nothing to criticize the Paper—far from it. But he thought that they all wished to add to the value of the proceedings by their personal opinions. Whether these differed from the Author's or whether they agreed, they were of value, and the wider the opinions the more valuable would the Proceedings of The Institution of Mechanical Engineers be. He had to thank the Chairman, who he believed was of the same profession as himself—an electrical man. Steel was one of the materials they had to study in the early stages, when they commenced to design revolving machinery subjected to heavy and varying forces. He was led to the study of steel through the mechanical side of electrical engineering. It was therefore a great pleasure to him to see Mr. Yerbury presiding that evening. Both the Author and the Chairman were entitled to the thanks of the Meeting. They had already recorded a vote of thanks to the Author of the Paper, and he hoped they would add to that another vote of thanks, to the Chairman.

The votes were carried with applause.

Communications.

Mr. H. C. ARMITAGE wrote that the subject of cutting tools possibilities was still in an undeveloped and unscientific condition. For instance, exhaustive as the Author's experiments had been, it would appear that they had yet to be repeated on cast-iron, phosphor-bronze, gun-metal, brass and aluminium. All of these metals were now in very common use, and the conditions for cutting aluminium were certainly vastly different from those

(Mr. H. C. Armitage.)
required for any other metal. He thought that investigation in respect of tools for aluminium would be very greatly welcomed by workshop engineers.

The engineering manufacturer would look at the subject of cutting tools in a somewhat different light from those whose business was not of such a repetitive nature. He would consider that all his cutting tools should be standardized, and would be willing to sacrifice minor conditions of cutting capability towards the attainment of that end. The prime necessity of standardization would surely be that he would want to keep in stock the fewest possible types of tools. To adopt certain standards required the consideration of about twelve variables, each of which might exert an influence upon the shape of the tool. He thought, especially in view of these investigations, that a large proportion of these variables might be neglected, and that the remaining ones might be averaged to produce certain results which could be applied definitely in making tool standards. One could then show results from these variables on isometric paper or possibly (and worse) on alignment charts. The chief thing that was required at the present time was to know what kind of a tool to use for certain material specifications. He had thought several times that it might be possible to tabulate and standardize tools by means of the Brinell hardness number of the material to be operated on, but unfortunately the element of toughness entered to spoil this very easily arranged shop procedure. They had not yet got any standards of toughness, so that suggestion was impracticable, although the modern impact test might perhaps be used as a rough guide. It still, therefore, seemed impossible to specify with any degree of scientific accuracy what tool, what speed, and what feed, were the most economical for any material.

Manufacturing practice also made further requirements in respect of limiting cutting speed which did not appear to have been considered in the Author's experiments and results. The limiting value of the cutting speed was governed by two things:—

(1) The shortness of the time taken to replace and reset a

worn tool with a new one, thereby neglecting time for grinding when the tools were given out in batches, and reground in a special shop devoted to the purpose.

(2) The facilities which were available for clearing the chippings. On speeds beyond 80 feet per minute, it was almost necessary to protect the operator on many classes of steel.

The first factor would cause them to raise their cutting speed, the second one to reduce it. The first consideration would show that the life of the tool could almost be ruled out of calculation, because assuming figures, if a tool running at 50 feet required changing in two hours, it was obviously more economical to run at 100 feet and change every half hour. Under ordinary workshop conditions this would not be an economy, and the longer life was more to be desired.

He did not notice any reference to experiments for chatter upon the life of tools, and would suggest that this could be suitably experimented upon by trying a duration test with different amounts of overhang. He would also like to know if anything had been done with welded tools; and whether the weld acted as an insulation against the conduction of heat from the cutting edge?

Mr. C. HUMPHREY WINGFIELD thought that the test of compressed air as a coolant, described on page 814, was less satisfactory than the other tests described in the Paper, which were practically beyond criticism. After passing through 45 yards of ½-inch pipe, the loss of head would probably be too great to leave much pressure when issuing from so large a nozzle. As the cooling effect depended upon the work done on the atmosphere by the sudden expansion of the compressed air, such a serious loss of head as probably occurred before the final expansion took place would rob the air of much of its cooling power. He thought a larger pipe (say 1¼-inch bore) should be used for such a long distance or, failing that, a very much smaller nozzle.

While the experiments showed clearly that a given colour did not show maximum cutting efficiency with all steels alike, it would

(Mr. C. Humphrey Wingfield.)

seem that the appearance of the colour noticed with a particular steel when cutting a little fast should be a useful warning that this speed had been passed when working on steel of the same kind and condition, and using similar tools.

The effect of different rake-angles and of various radii for the tool-point appeared to be the principal results of this painstaking and valuable research; it was rather surprising that (page 788) doubling this radius had a greater effect for good on tools of smaller section. It rather suggested, on principles of similarity, that $\frac{1}{4}$ inch was too small a radius for the points of the heavier tools.

The AUTHOR wrote that, in replying to Mr. Vernon's remark (page 828) in regard to the comparatively low-cutting speeds given in the Paper, and the comparatively high-cutting speeds used in automatic machine and turret-lathe practice, it should be pointed out that the Paper dealt with finishing cuts of a definite kind, and a kind which was not used to any great extent in the department of engineering-workshop practice referred to by Mr. Vernon. Further, such high-cutting speeds as were employed in turret-lathe practice were only possible when steadies, particularly of the roller type, were used, these steadies acting incidentally as burnishing tools, and so adding a finish to the surfaces formed by the cutting tools. Referring to the question of the useful life of the cutting edge of a lathe-tool and its bearing upon the productivity of machine-tools of the automatic and turret-lathe types, as raised by Mr. Vernon, it appeared that this was a most important question and one which demanded further investigation, particularly in regard to the influence of periodic cooling, such as occurred in this kind of workshop practice, upon the life of the tool under given constant conditions, including the cutting speed, the feed per revolution, the depth of cut, the shape of the tool-nose, the material being operated upon, and the durations of both the active and rest periods of the tool.

The question of the influence of the height of the cutting edge of a tool upon the durability of the edge—and the power-

consumption of the tool—was dealt with in the Paper from the point of view of testing and not from that of manufacturing, the objects of the tests made in this connexion being to discover whether the actual position of the cutting edge of the tool with respect to the axis of the test-bar or work-piece being machined, had any influence whatever upon the life of the cutting edge of the tool or the power consumption for any given rate of removal of material from the bar. Mr. Vernon's objection to the general use of the expression "height of the cutting edge" might be well sustained; but it was a little difficult to conceive of a simpler description of the condition represented, and in any case Fig. 85 (page 789) clearly indicated the case. It was fairly obvious that, under standardized conditions in a manufacturing establishment, there was only one practical position for a lathe cutting tool in the machine, and that was such that the angles actually ground on the tool were the angles actually operating when it was in action. Any other condition only led to indefiniteness and confusion.

The question of the durability of the cutting edges of standardized cutting tools, such as reamers and broaches for machining standardized parts under the interchangeable system to within definite and fixed limits of accuracy, as raised by Mr. Pearson, was an important one, as it was directly related to the operating value of these tools, measured in terms of the number of parts machined by them which would pass the test of inspection. This, however, appeared to be a matter that could best be investigated in a modern engineering works, working in conjunction with the laboratory attached to a scientific institution.

In reply to Mr. Herbert's criticism (page 834) regarding the lowness of the cutting speeds employed in the durability tests on the lathe finishing tools, it should be pointed out that these tests were made with cutting speeds which did not exceed the critical values as determined by means of the preliminary surface-finish tests, it being assumed that any information obtainable for cutting speeds above the critical values would not be of any utility from either the practical or scientific point of view, so far as finishing cuts of the description indicated in the Paper were concerned.

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For this reason, the fact that the durability curves given on page 768 would apparently cut the vertical co-ordinate axis at speeds between 30 and 40 feet per minute was not without significance, since the critical values of the cutting speed, that is, the cutting speeds which did not admit of an acceptably smooth finish being obtained and which, therefore, was of no practical value, practically lay between these two limits for the plain carbon and super high-speed steel tools working on the hard steel bar, as indicated in Tables 2A and 2C (page 763). In regard to the plotting of points by Mr. Herbert on his durability curve from data taken from the Paper, and Mr. Herbert's argument that the range of cutting speeds covered by these data was too small, and that the actual cutting speeds represented by them were too low, it was interesting to note that the opposite argument was employed in the discussion on the original Paper in 1913, namely, that the cutting speeds employed were not sufficiently low to enable the deflection in the durability curve to be obtained.

Mr. Kayser's method of estimating ball-impression hardness (page 831), appeared to be a very ingenious one; but it should be observed that the conditions under which the impression was formed in the case of Mr. Kayser's apparatus were essentially different from those obtaining in the case of the standard Brinell machine. For this reason it was doubtful on a *prima facie* consideration of the matter whether the results obtained with this apparatus would be comparable with those obtained with the standard machine, though the former might be strictly comparable amongst themselves. In any case, it should be possible to calibrate the apparatus working on the dynamic principle with the standard machine whose principle of action was compounded of both the dynamic and static principles.

In reply to Mr. Dempster Smith (page 838), it should be stated that the subject matter of the Paper had reference only to experiments made on plain carbon-steel test-bars, and that the results given in the Paper were not intended to be applicable to the case of the newer alloy steels, the qualities of which, from the machining point of view, required special investigation.

Furthermore, the test-bars employed in the experiments were all in the normalized condition, so that the formula given on page 777 should not be used in the case of heat-treated non-alloy steel or in the case of alloy steel, heat-treated or otherwise. Regarding Mr. Smith's reference to the fact that the durability of the cutting edges of the lathe finishing tools at cutting speeds above the critical value were not given in the Paper, it was not thought at the time of the experiments that such results would be of any use to anybody interested in either the practical or scientific aspect of cutting, and since then no valid reason to the contrary had been adduced. In the preliminary selective tests, each tool machined a surface of about 20 square inches, though this must not be taken as a measure of the durability of the cutting edges of the tools, since the question of durability was not the one considered in connnexion with the preliminary tests.

With regard to the "associated-speed" formulæ, the two forms 5 and 6 given on page 777, were for the case of tools of varying sections and with nose-radii obeying the law: $r = \sqrt{\frac{a}{S}}$, where $r =$ the nose-radius in inches and $a =$ the cross-sectional area of the tool-steel in square inches. The corresponding formula for modern super-high-speed steel with the nose-radius independent of the tool-steel section was

$$S = \frac{0 \cdot 00683\,(65 - T)\,(T + 20)\left\{\left(\frac{8a}{3}\right)^{\frac{1}{5r}} \times r\right\}^{\frac{1}{9}}}{\sqrt[3]{F^2 D}},$$

where S = the associated cutting speed, in feet per minute; T = the tensile strength of the steel being machined; a and r are the tool-steel section and nose-radius respectively; F = the feed in inches per revolution; and D = the depth of cut in inches.

Colonel Crompton's case (page 842), appeared to be one of very fine roughing cuts rather than that of finishing cuts of the description given in the Paper, the latter being cuts which would produce finished surfaces that did not show any feed marks irrespective of the magnitude of the feed. In the Tables appended to the Reply (pages 904–907), would be found cutting speeds

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corresponding to those used under the conditions quoted by Colonel Crompton and Mr. Vernon, that is, with very fine feeds. The question of chatter in cutting was undoubtedly a most important one in many cases, as it affected the nature of the finished surface, but it should be pointed out that, whilst chatter was probably set up by actual cutting conditions, it was aggravated by the design, proportions, and arrangements of the elements of the machine in which the tool was working. One thing, however, appeared very certain, and that was that the tendency to set up chatter in a cutting operation was related in some way to the composition of the steel being machined and to the heat treatment that the steel had received prior to its being operated upon.

In reply to Mr. Adamson's request (page 847), for a description of the lathe on which the lighter tests were carried out, this machine was a six-inch centre lathe made by Messrs John Lang and Sons, of Johnstone, and fitted with their variable-speed mechanism in the driving headstock, the total weight of the machine being about 2,600 lb. It was driven by a belt $2\frac{1}{4}$ inches wide, the speed range of the driving spindle being from 6 r.p.m. to 200 r.p.m. The bed was $11\frac{1}{4}$ inches wide on the top face and $8\frac{3}{8}$ inches deep, the contact area between the top face of the bed and the underside of the saddle of the slide-rest being about 70 square inches. The front bearing of the driving spindle was 3 inches in diameter and in length. The general condition of the lathe was good.

With reference to Mr. Adamson's remarks concerning the experiments on the position of the cutting edge of a lathe turning tool with respect to the axis of rotation of the test-bar, it might be observed that four sets of experiments were made all together, the tools being ground so that all the possible variations in regard to the clearance and rake angles were covered. A brief tabulated summary of the results of these tests is given on page 901. In this Table the letter C indicated that the particular angles of the tools of the set were constant, whilst those marked V were variable as was shown in the Paper. In regard to the order of the

tools for durability and net power consumption, the letters A, N, and B, stood for the positions above the centres, on the centres, and below the centres respectively, whilst the tool marked 1 under "durability" had the longest life, and that marked 1 under "net power consumption" was associated with the lowest net consumption of power.

In regard to the question of the imperfections in high-speed

TABLE 26.

Set of Experiments.	Rake.		Clearance.		Order of Tools for Durability.			Order of Tools for Net Power Consump.		
	Ground.	Operative.	Ground.	Operative.	A	N	B	A	N	B
1	C	V	C	V	1	2	3	1	2	3
2	C	V	V	C	2	1	3	1	2	3
3	V	C	C	V	1	2	3	3	2	1
4	V	C	V	C	1	2	3	2	3	1

tool steels, as raised by Dr. Rogers (page 879), and their effect on the tendency of cutting tools to break, it should be noted that in solid-bar cutting tools of the lathe type the flaws chiefly found were either longitudinal or transverse, the former apparently being derived from seams present in the bars as received from the rolling mills, and the latter from cracks which were largely the result of faulty forging. Both forms were, of course, affected by the hardening operations, and each had its own influence on the tendency possessed by the tool to fracture. In tools actually fractured during the cutting operations, it was found that the fractured surface always tended to lie parallel to the cutting edge of the tool; hence the change in tool form that Dr. Rogers suggested would have the immediate result of reducing the extent of the most highly stressed section, and so increasing the specific

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stress in that section, whilst the ultimate effect would be to increase the tendency of the tool to fracture along that section. It was true, of course, that this tendency to fracture was influenced by the presence of cracks or planes of weakness, due to imperfections in the steel, and hence the relation between the directions of the cracks and the direction of this section could not be ignored, but probably the exact condition of the nose of the tool as a cantilever beam was quite as important as the directions of the flaws. The tool should, therefore, be set up with as little overhang as possible, and the base of the tool should be quite flat and rest evenly on its support. Failing this latter condition, either the tool would be initially stressed in tightening it up in the tool clamps of the slide-rest, or the bending moment induced in the nose of the tool by the cutting forces would be increased to a far greater amount than would be represented by the overhang of the tool.

Another point which called for notice was that the whole nose of a high-speed steel lathe turning tool was usually hardened, hence its brittleness was greater than that of the unhardened shank of the tool and its capacity for allowing for small deflections was less. This was particularly important when viewed in relation to the fact that all cutting action was intermittent in the sense that the cutting forces brought into action were variable within cycles of changes, and so constituted a case of repetition of stress.

Regarding Mr. Armitage's statements (page 893), it was frankly recognized that the scientific investigation of the subject of cutting tools was by no means complete, and that it was eminently desirable that the work should be extended to other materials of engineering construction. At the same time, it should be pointed out that the subject was such a very large one, and the work of investigation so very costly, that the work could only be expedited by the whole-hearted co-operation of engineering manufacturers and the research departments of institutions like the one wherein the work described in the Paper was done. Of all the many pressing problems in the domain of cutting-tool operation which demanded attention, the most urgent appeared to be in connexion with the nature of the many varied conditions which were grouped

under the generic name "cutting action"; and an investigation was urgently needed to determine the exact manner in which a tool removed, by the process of cutting, material of the several different kinds used in mechanical engineering practice. The question of the relation between cutting efficiency and Brinell hardness had been considered by Dr. J. O. Arnold, of the University of Sheffield, for the case of high-speed steel tools, and his conclusion was that the Brinell hardness of a high-speed steel tool in the cold state did not bear any definite or reliable relation to its cutting efficiency. It therefore appeared that some other method of obtaining a simple measure of the cutting capabilities of steel cutting tools would have to be sought before real dependability was reached.

In regard to Mr. Wingfield's reference (page 896) to the effect of a change of nose-radius upon the cutting ability of a lathe turning tool, it should be remarked that, in connexion with ordinary rough-turning practice in the engine and similar lathes, the rational deduction to draw from the results of the test was that the nose-radius should bear some definite relation to the section of the tool-steel employed, so that as the tool section was increased, so was the nose-radius. As a matter of interest and fact, this principle was adopted in the nose-radius and tool-section tests of the original Paper presented by Dr. Ripper and the Author to The Institution in 1913.

(*For Appendix to Author's Reply, see overleaf.*)

APPENDIX TO AUTHOR'S REPLY.

TABLE 27.

Table of Cutting Speeds for Super High-Speed Steel Lathe Roughing Tools Working on Plain Carbon-Steels with the Use of a Coolant.

1. Tool Section = $\frac{1}{2}$ inch square. Nose Radius = $\frac{1}{16}$ inch.

Depth of Cut. Inch.	Feed per Revolution. Inch.	Cutting Speed, in Feet per Minute, when working on		
		Mild Steel.	Medium Steel.	Hard Steel.
$\frac{1}{16}$	$\frac{1}{64}$	309	283	180
	$\frac{1}{32}$	196	179	114
	$\frac{1}{16}$	124	112	71
	$\frac{1}{12}$	101	92	58
	$\frac{1}{8}$	78	71	45
	$\frac{1}{6}$	64	58	37
$\frac{1}{8}$	$\frac{1}{128}$	390	358	227
	$\frac{1}{64}$	244	223	142
	$\frac{1}{32}$	155	141	90
	$\frac{1}{16}$	98	89	57
	$\frac{1}{12}$	81	74	47
	$\frac{1}{8}$	61	56	35
$\frac{3}{16}$	$\frac{1}{128}$	336	310	196
	$\frac{1}{64}$	212	193	123
	$\frac{1}{32}$	137	124	79
	$\frac{1}{16}$	85	77	49
$\frac{1}{4}$	$\frac{1}{128}$	309	282	179
	$\frac{1}{64}$	194	178	113
	$\frac{1}{32}$	123	112	71

TABLE 28.

Table of Cutting Speeds for Super High-speed Steel Lathe Roughing Tools Working on Plain Carbon-Steels with the Use of a Coolant.

2. Tool Section = $\frac{3}{4}$ inch square. Nose Radius = $\frac{3}{32}$ inch.

Depth of Cut. Inch.	Feed per Revolution. Inch.	Cutting Speed, in Feet per Minute, when working on		
		Mild Steel.	Medium Steel.	Hard Steel.
$\frac{1}{16}$	$\frac{1}{64}$	373	323	206
	$\frac{1}{32}$	225	206	131
	$\frac{1}{16}$	142	128	82
	$\frac{1}{12}$	116	105	67
	$\frac{1}{8}$	90	81	52
	$\frac{1}{6}$	74	67	43
$\frac{1}{8}$	$\frac{1}{128}$	460	410	265
	$\frac{1}{64}$	285	257	165
	$\frac{1}{32}$	178	162	104
	$\frac{1}{16}$	115	102	66
	$\frac{1}{12}$	94	84	54
	$\frac{1}{8}$	71	64	41
$\frac{3}{16}$	$\frac{1}{128}$	390	354	226
	$\frac{1}{64}$	245	222	142
	$\frac{1}{32}$	159	142	92
	$\frac{1}{16}$	100	87	57
	$\frac{1}{12}$	82	73	47
$\frac{1}{4}$	$\frac{1}{128}$	355	323	206
	$\frac{1}{64}$	226	206	132
	$\frac{1}{32}$	141	128	82
	$\frac{1}{16}$	90	81	52
$\frac{3}{8}$	$\frac{1}{128}$	312	282	181
	$\frac{1}{64}$	197	177	114
	$\frac{1}{32}$	124	112	72

TABLE 29.

Table of Cutting Speeds for Super High-speed Steel Lathe Roughing Tools Working on Plain Carbon-Steels with the Use of a Coolant.

3. Tool Section = 1 inch square. Nose Radius = $\frac{1}{8}$ inch.

Depth of Cut. Inch.	Feed per Revolution. Inch.	Cutting Speed, in Feet per Minute, when working on		
		Mild Steel.	Medium Steel.	Hard Steel.
$\frac{1}{16}$	$\frac{1}{64}$	418	376	240
	$\frac{1}{32}$	262	239	152
	$\frac{1}{16}$	164	150	95
	$\frac{1}{12}$	134	123	78
	$\frac{1}{8}$	105	94	60
$\frac{1}{8}$	$\frac{1}{64}$	330	298	190
	$\frac{1}{32}$	208	188	120
	$\frac{1}{16}$	131	119	76
	$\frac{1}{12}$	107	98	62
	$\frac{1}{8}$	84	75	49
$\frac{3}{16}$	$\frac{1}{64}$	283	257	169
	$\frac{1}{32}$	179	161	102
	$\frac{1}{16}$	115	106	67
	$\frac{1}{12}$	94	86	55
	$\frac{1}{8}$	72	65	42
$\frac{1}{4}$	$\frac{1}{64}$	262	238	152
	$\frac{1}{32}$	164	150	95
	$\frac{1}{16}$	103	94	60
	$\frac{1}{12}$	86	78	49
	$\frac{1}{8}$	66	60	38
$\frac{3}{8}$	$\frac{1}{128}$	348	320	204
	$\frac{1}{64}$	224	204	131
	$\frac{1}{32}$	143	125	83
	$\frac{1}{16}$	92	78	53
	$\frac{1}{12}$	74	68	43
$\frac{1}{2}$	$\frac{1}{128}$	329	298	189
	$\frac{1}{64}$	207	187	119
	$\frac{1}{32}$	129	118	75
	$\frac{1}{16}$	83	75	47

TABLE 30.

Table of Cutting Speeds for Super High-speed Steel Lathe Roughing Tools Working on Plain Carbon-Steels, with the Use of a Coolant.

4. Tool Section = $1\frac{1}{4}$ inch square. Nose Radius = $\frac{5}{32}$ inch.

Depth of Cut. Inch.	Feed per Revolution. Inch.	Cutting Speed, in Feet per Minute, when working on		
		Mild Steel.	Medium Steel.	Hard Steel.
$\frac{1}{8}$	$\frac{1}{64}$	351	322	205
	$\frac{1}{32}$	225	203	129
	$\frac{1}{16}$	140	129	82
	$\frac{1}{12}$	115	106	67
	$\frac{1}{8}$	88	82	51
$\frac{3}{16}$	$\frac{1}{64}$	305	277	177
	$\frac{1}{32}$	189	173	110
	$\frac{1}{16}$	124	112	72
	$\frac{1}{12}$	102	93	59
	$\frac{1}{8}$	78	71	45
$\frac{1}{4}$	$\frac{1}{64}$	282	257	164
	$\frac{1}{32}$	176	162	103
	$\frac{1}{16}$	110	101	64
	$\frac{1}{12}$	92	84	53
	$\frac{1}{8}$	71	65	41
$\frac{3}{8}$	$\frac{1}{64}$	243	222	141
	$\frac{1}{32}$	154	141	90
	$\frac{1}{16}$	101	89	57
	$\frac{1}{12}$	83	74	47
	$\frac{1}{8}$	62	56	35
$\frac{1}{2}$	$\frac{1}{128}$	353	321	204
	$\frac{1}{64}$	229	208	132
	$\frac{1}{32}$	141	128	81
	$\frac{1}{16}$	88	81	51
	$\frac{1}{12}$	72	67	42
$\frac{5}{8}$	$\frac{1}{128}$	334	302	192
	$\frac{1}{64}$	208	189	120
	$\frac{1}{32}$	131	120	76
	$\frac{1}{16}$	83	76	48

MEMOIRS.

WILLIAM ARMSTRONG was born at Wingate, Co. Durham, in 1846. He was educated at Rossall School and afterwards at the University of Edinburgh. His apprenticeship as a mining engineer was served with the late Mr. John Daglish at the Marquess of Londonderry's Collieries, and subsequently he succeeded his father as agent at Wingate Colliery. This position he resigned in 1909 in order that he might devote his whole services to the firm of William Armstrong and Sons, consulting mining engineers of Newcastle-on-Tyne. He was a Justice of the Peace for the County of Durham, and was for many years consulting engineer to the Pemberton Collieries in Lancashire. He became a Member of this Institution in 1876; he was also a Member of the Institution of Civil Engineers and of the North of England Institute of Mining and Mechanical Engineers, of which latter Institute he was President for the two years 1898–1900. His death took place at Gosforth on 30th March 1918, in his seventy-second year.

Sergeant GEORGE STANLEY DENNIS, R.F., was born at Thornaby-on-Tees on 31st May 1877. He was educated at the City of London School, and was articled in 1894 for three years with Messrs. Garbe, Lahmeyer and Co., electrical engineers, Aachen, Germany. He was then employed for over two years as draughtsman and constructing engineer to Mr. E. Linell, engineer, Berlin, and in 1900 was appointed constructing engineer to the British Westinghouse Electric and Manufacturing Co., Ltd., where he was engaged on several large installations. He joined the Army on 1st September 1914, and had seen much service. He was in the Public Schools Battalion of the Royal Fusiliers, and was gazetted into the Durham Light Infantry. Latterly he was in the Intelligence Corps at Cologne,

where his death took place from pneumonia on 1st July 1919, at the age of forty-two. He was elected a Graduate of this Institution in 1901 and an Associate Member in 1903.

Mephan Ferguson was born at Falkirk, Scotland, on 25th July 1843, and was educated at the Falkirk School and at Barnet School, Melbourne. From 1860 to 1862 he served an apprenticeship with Mr. John Fleming, of Ballarat, which was followed by one with Mr. John Price, of the same town, where for twelve years he was engaged in constructing and erecting iron box and lattice girders for bridges and general mining work. In 1873 he started in business on his own account in Melbourne, as general engineer, ironfounder, boiler-maker, pipe-founder, &c., and carried out a large number of contracts for the Government. He invented in 1895 the locking-bar or rivetless pipe, and the machinery for making the pipes, which were adopted for the great Coolgardie Water Scheme of 350 miles of 30-inch diameter pipes. Subsequently his rivetless pipe has been used on many Government and Municipal works in Australia, and at the Bombay Waterworks, where he erected a plant for the purpose. The pipe has also been adopted for gas and water schemes in England, the United States, Canada, and elsewhere. In connexion with his widespread interests he travelled considerably. His death took place in Melbourne on 2nd November 1919, at the age of seventy-six. He became a Member of this Institution in 1907.

Robert Henry Fowler was born at Melksham, in February 1851, and was the nephew of Mr. John Fowler who was the inventor of the steam plough and the founder of the Steam Plough Works, at Leeds. He entered the Steam Plough Works in 1874, and made many journeys for the Firm, mainly in tropical countries, between 1880 and 1910. From 1888 he was the controlling and organizing head of Messrs. John Fowler and Co. (Leeds), Ltd., and under his administration the works have been completely modernized and brought up to date. His acquaintance with the application of mechanical power to the cultivation of land

was extensive and thorough, and his agricultural experience covered a wide range of climates. In 1903 he read a Paper before this Institution on "Roofing existing Shops while Work is proceeding." His death took place in London on 4th May 1919, at the age of sixty-eight. He became a Member of this Institution in 1894.

Major THOMAS EDWARD GOODEVE, O.B.E., R.E., was born in London on 5th August 1876. He was educated at St. Paul's School and at the Royal College of Science and School of Mines. In 1896 he became a premium apprentice in the locomotive works of the London and North Western Railway at Crewe, and on its completion he entered the drawing office of the same works, subsequently becoming in January 1902 assistant manager in the locomotive works. This position he held until 1909 when he was transferred to the Outdoor Department and later to the Steel Works. Two years later he became assistant manager on locomotive repairs at Crewe and out-station erecting shops, and in December 1913 he was appointed works manager and assistant locomotive superintendent at the Inchicore Works of the Great Southern and Western Railway, Dublin. In 1916 he joined the Royal Engineers and served in Palestine from January 1917 until 26th January 1918, when he was accidentally killed at Baalbeck, Syria, at the age of forty-one. On two occasions he was personally congratulated by the Commander-in-Chief for his efficient work. He became an Associate Member of this Institution in 1906, and a Member in 1914.

ALFRED HILLYARD MITCHELL was born at Stapleford, near Cambridge, on 23rd May 1871, and was educated at a private school in Cambridge. On leaving school he was engaged for a time in the coal business in Ipswich, and then joined the staff of Messrs. Cory Bros., Ltd., colliery proprietors, where he was engaged in the drawing office and on various engineering work. In 1899 he was employed for about a year as engineer to the Cromptwylt Lead and Zinc Mines, near Aberystwyth, and then became engineer to the London Grain Elevator Co., Ltd., holding

this position until 1911, when the Company was merged in the Port of London Authority. He was then appointed resident engineer of the Bulk Grain Engineering Division, which he held until the time of his death. He was well known as an expert in grain-handling machinery, and brought out a cantilever elevator, which was a considerable advance on the machinery in use at that time for the discharge of grain from ships. He was also the inventor of a compensated rapid luffing crane. His death took place at Sidcup on 24th September 1919, at the age of forty-eight. He became a Member of this Institution in 1911.

RONALD ALLPORT NEEDHAM was born at Alvaston, near Derby, on 19th April 1870. He was educated at Rugby School, and went in 1887 as a pupil with Messrs. Harland and Wolff, Belfast, where he passed through the shops and drawing-office, having for a time the charge of the Testing Department. After a year at sea, he was engaged at the works of Messrs. Vickers, Sons and Maxim, Barrow-in-Furness, on inspecting material, running torpedo-destroyer trials, etc. Three years later he was employed by Messrs. Francis Morton, Ltd., of Garston, to take charge of the galvanizing department and to supervise outside erection work. In 1900 he transferred his services to the British Westinghouse Co., at Pittsburg and Manchester, where he was engaged on the lay-out and planning of the Trafford Park Works, after which he acted as assistant purchasing agent. In 1907 he became the proprietor of the works, etc., of Mr. W. H. Rowland, Bangor, N. Wales, yacht designer, builder, and engineer, which he managed, in addition to carrying out marine consulting work. His death took place at Liverpool on 20th May 1919, at the age of forty-nine. He was elected an Associate Member of this Institution in 1914.

HENRY HANDLEY PRIDHAM POWLES was born at Upper Clapton, London, on 4th August 1846. He was educated partly at private schools and partly at the Ipswich Grammar School. In January 1864 he was apprenticed to Messrs. E. R. and F. Turner, St. Peter's Ironworks, Ipswich, and on its completion in 1869 he went as

improver and engine-fitter to Messrs. Ransomes, Sims, and Head, Orwell Works, Ipswich. In 1871 he returned to Messrs. Turner's works and was employed in the drawing office and on work in various parts of the country. In the following year he entered their drawing office, becoming head draughtsman in 1876. This position he held until 1890, when he was appointed mechanical engineer to the Electric Standardizing and Training Institution, Faraday House, London, which had just then been started in temporary premises in the Adelphi. He arranged and fitted up the workshops at the new premises of the above Institution in Charing Cross Road, and remained there until January 1898 when he joined Sir Alexander Kennedy's staff as assistant and was put in charge of the drawing office. This post he held until January 1912, but until his death he was retained by Messrs. Kennedy and Donkin for research work and inspections. During 1916 and 1917 he was employed in inspecting constructional work and plant for one of the munition factories, and later he carried out very useful work on preparing a bibliography of Lubricants and Lubrication for the Scientific and Industrial Research Department. In addition to translating Dr. F. Kick's standard work on "Flour Manufacture" and H. Haeder's book on the Steam Engine, he was responsible for the revision and enlargement of D. K. Clark's "Mechanical Engineer's Pocket Book." In 1905 Mr. Powles prepared a work on the "History and Development of Steam Boilers," which is particularly valuable on account of its historical notes on the subject. His death took place in London, after a few months' illness, on 27th July 1919, in his seventy-third year. He was elected a Member of this Institution in 1891.

Benjamin Alfred Raworth was born at Chesterfield on 1st June 1849. He was educated at Chesterfield Grammar School and at Owens College, Manchester. His apprenticeship, which preceded his going to Owens College, was served at the works of Mr. Edward Hayes, of Stony Stratford. After taking his course of studies at Owens College he went for a further training of three years at the works of Messrs. Wren and Hopkinson, Manchester,

and while there he secured a Whitworth Exhibition in 1868, and a Whitworth Scholarship in 1871. In the same year he became a private assistant and draughtsman to Sir Joseph Whitworth, and held this position until the following October when he became draughtsman and assistant engineer at the works of Messrs. Siemens Brothers at Woolwich. In 1874 he left this firm to join his brother, the late Mr. J. S. Raworth, at Manchester in the development of some cotton-spinning machinery, and during this period he brought out, in conjunction with his brother, two inventions, one for winding yarns and the other for looms. He returned to London in 1880 and joined the staff of the late Sir (then Mr.) W. Lloyd Wise as chief technical assistant, his work comprising the preparation of specifications for patents, drafting cases for the opinion of counsel, etc. During this time he also prepared the abstracts of electrical patents for the late Mr. Dredge's book on "Electrical Illumination," and the abstracts of patents which appeared weekly in *Engineering*. It was this work which led to his joining the staff of *Engineering* in 1882. Occupying at first a junior position he rose by degrees until, on the death of Mr. Dredge in 1906, he was appointed joint editor with Dr. William H. Maw (Past-President). In addition to his editorial work he wrote a number of articles during 1901–1904 in *Traction and Transmission*, a monthly supplement to *Engineering*. His death took place, after a long and severe illness, on 30th September 1919, at the age of seventy. He was elected a Member of this Institution in 1906; he was also a member of the Iron and Steel Institute and of the Institute of Metals.

FREDERICK HORACE REED was born in London on 3rd September 1898, and was educated at the Latymer Upper School, Hammersmith. In August 1916 he began an apprenticeship of five years in the marine engine department of the Naval Construction Works, Barrow-in-Furness, and during the same period he studied at the Barrow Technical School. In May 1918 he joined the Royal Air Force, becoming a Corps Observer, but later in the year he was wounded in a fight over the German lines.

Subsequently, it was reported that he had died from his wounds and was buried by the Germans at the village where the machine came down. His death took place on 23rd October 1918, at the age of twenty. He became a Graduate of this Institution in May 1918.

Charles Thomas Roberts was born at Alderton, Suffolk, on 16th October 1861, and was educated at Kesgrave Hall School, Suffolk. In April 1877 he was articled for three years to a Civil Engineer in Brussels, and during part of the period he worked in the shops of Messrs. Mening Frères at Carreghem, near Brussels. In 1880 he became a draughtsman in the works of Messrs. E. R. and F. Turner, of Ipswich, where he remained until 1887, when he went to South Africa to represent the firm in the Transvaal, and continued in this work until 1891. He then set up in practice as consulting engineer in Johannesburg, and in this capacity he designed surface mining plants, and supervised their erection, in some of the principal mines. In 1895 he was appointed consulting mechanical engineer to the Johannesburg Consolidated Investment Co., and in the following year he acted in a similar capacity to the French South African Development Co., in Rhodesia, and in 1899 to the United Excelsior Mines, and other companies. He returned to England in 1904, and two years later he proceeded to Mysore, India, to take up the post of Chief Engineer to the Champion Reef Gold Mining Co., where he designed and carried out the extensive re-equipment of the whole plant. He held this position up to the time of his death, which occurred suddenly at Madras on 20th November 1918, at the age of fifty-seven. He became an Associate Member of this Institution in 1893, and a Member in 1907. He was also a Member of the Federated Institution of Mining Engineers.

Colonel William Shanks, V.D., was born at Johnstone, Renfrewshire, in 1838. He was educated at Irvine Academy and Merchiston Castle, and afterwards served his apprenticeship in his father's firm, namely, that of Thomas Shanks and Co., makers of

heavy machine-tools, Johnstone. On the retirement of his father in 1880 he assumed the control of the business and interested himself greatly in the improvement of heavy machine-tools. Two years previously he introduced a new design of heavy boring machine which worked successfully in Great Britain and the United States. He also originated the double-bed type of lathe which effected a greatly improved distribution of cutting tools and their strains, and made possible the building of the huge lathes at present in use. Under his direction a very heavy planing machine although of moderate dimensions, was made for planing the first armour-plates applied to warships, while his other activities included a machine for making horse-shoes. By 1883 the business had so grown that a large extension became necessary, and in that year the firm erected new works on a new site. These works were one of the first in the country to be lighted by electricity. Although for some years before his death he had ceased to be responsible for design, he continued as head of the firm. His death took place at Johnstone on 29th July 1919, in his eighty-first year. He was elected a Member of this Institution in 1884.

William John Stephenson-Peach was born at Derby on 10th March 1852. He received his engineering training at the Atlas Works, Derby, and at Messrs. J. and G. Thompson's shipbuilding works, Glasgow. In later years the idea occurred to him of starting practical engineering shops at Public Schools, and in that connexion he was associated with Repton School in 1888, and afterwards with Cheltenham and Malvern Colleges. During that period he brought out the Repton oil-engine, two-speed gear for cycle-cars, motor-cars and ploughs, etc. He was interested in pisciculture, and, after experimenting largely, he formed the Trent Fish Culture Co. in Derbyshire, of which he was managing director until his death. When war broke out he added munition work to his college duties, and under the strain his health broke down. The last weeks of his life were spent in helping disabled soldiers to earn a living in the toy workshops at Bournemouth, where his death took place

from influenza on 4th March 1919, in his sixty-seventh year. He became a Member of this Institution in 1888.

Ernest Sidney Strong was born in Bombay on 16th July 1868. He was educated at various private schools in England and at the Glasgow and West of Scotland Technical College during the period of his apprenticeship, which was served with Messrs. Alley and MacLellan, Glasgow, during 1883–1888. In the following year he worked in the firm's drawing office, and in the erecting shop, and spent six months in the drawing office of the North British Railway at Cowlairs. In January 1891 he joined the locomotive staff of the Indian State Railways, and was transferred in the following year to the North Western Railway. He officiated for three months in 1896 as district locomotive superintendent of the Karachi District, and during 1897–8 acted in the same capacity in the Sukkur District. He was next appointed district locomotive superintendent of the Saharanpur District and Locomotive Shops, and held this post until 1902 when he was transferred to the Oudh and Rohilkund Railway, having charge of the Moradabad District. In February 1911 he returned from leave and was posted as district locomotive superintendent at Rawalpindi. There he served, except for a brief interval in England, throughout the War, assisting the military and civil authorities. Subsequently he was transferred to Saharanpur where his death took place on 9th April 1919, in his fifty-first year. He joined the North Western Railway Volunteer Rifles in 1892, and had the rank of Major in the Corps, in which he was serving at the time of his decease. He also held the V.D. Decoration. He was elected a Member of this Institution in 1910.

Robert Francis Stafford Thompson was born at Morecambe on 24th January 1890. He was educated at the Royal Grammar School, Lancaster, and Aylwin College, Arnside. In 1908 he began a three-years' apprenticeship in the locomotive works of the Furness Railway, and studied at the Barrow Technical School in the evenings. On the completion of his apprenticeship he remained

with the Company as Inspector of Materials. Subsequently he had charge of the hydraulic engines at Barrow Docks, and later of the locomotive sheds at Carnforth. This post he held to the time of his death, which took place from influenza at Bolton-le-Sands on 11th November 1918, in his twenty-ninth year. He was elected an Associate Member of this Institution in 1915.

Thomas Wright was born at Wakefield on 30th November 1866. He was educated at the school of the Leeds Mechanics' Institute and at the Yorkshire College, Leeds. His apprenticeship was served from 1882 to 1887 in the shops and drawing-office of Messrs. Kitson and Co., Leeds, and on its completion he remained five years longer in the drawing-office. In 1892 he was engaged as a draughtsman in the steel works of Messrs Bolckow, Vaughan and Co., Ltd., Middlesbrough, and in the following year he became chief draughtsman at the Holderness Foundry of Messrs. Priestman Brothers, Ltd., Hull, where he remained for five years. In 1898 he transferred his services to Messrs Siemens Brothers and Co., Ltd., Woolwich, subsequently becoming production department manager, and in 1903 he was appointed works manager with the Premier Gas Engine Co., Ltd., Sandiacre, near Nottingham, which position he held until 1905, when he became general manager of the Dowson and Mason Gas Plant Co., Levenshulme, Manchester, and held this position for fourteen years. His death took place in London on 31st January 1919, at the age of fifty-two. He became a Member of this Institution in 1903.

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Fig. 8. *Load on Demountable Body in course of transition from ground to Electric Chassis (Edison) with self-contained lifting gear, operation completed in 2¼ minutes.*

(For Details of Lifting Gear, see Fig. 7.)

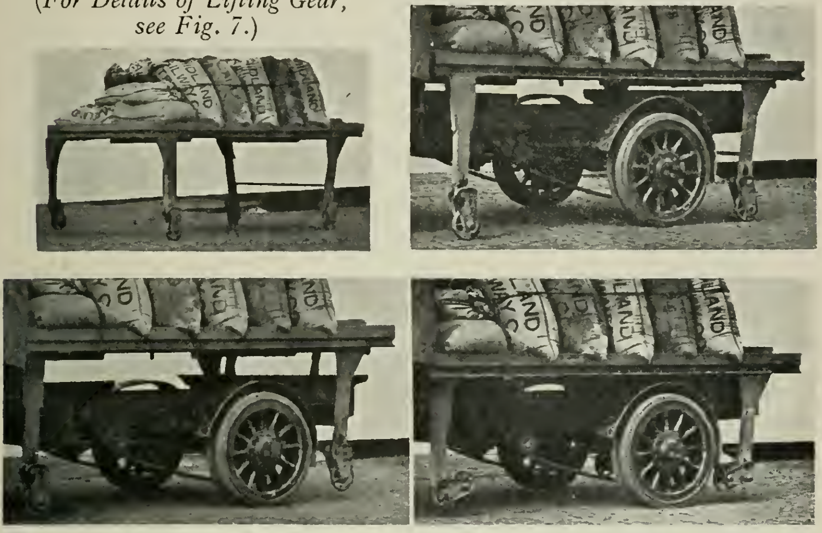


Fig. 9. *3-ton Load being transferred to Motor Lorry from Loading Truck.*

(Stamper.)

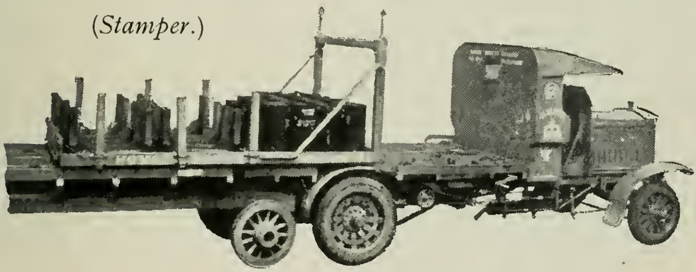


Fig. 12. *Load on D.C.C. Body in course of transition from 4-ton Lorry (Edison) to Tender Lorry, operation completed in 2½ minutes.*

Fig. 13. *6-ton Wagon and Trailer (Sentinel).*

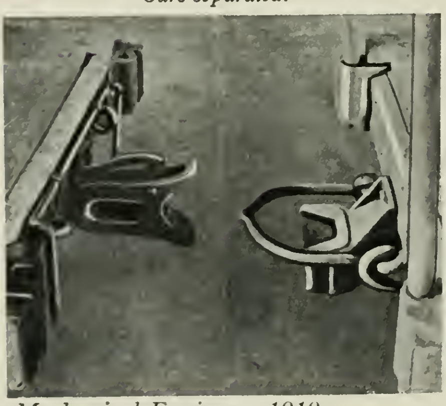
Trailers (Bristol Wagon Co.).

Fig. 14. *Tipping.*

Fig. 15. *With Steering Gear.*

Fig. 16. *Automatic Coupler in use on small Warehouse Trollies.*

Cars separated.



Cars coupled.

Fig. 17. *Tractor, with Semi-Trailer (Knox). Uncoupled and coupled.*

Fig. 18. *Street Cleaning Tractor and Semi Trailer (G. V. Co.).*

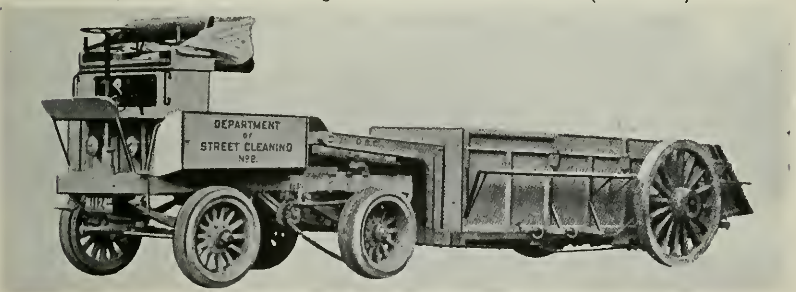


Fig. 19. *4-Wheel Refuse Wagon, drawn by Electric Tractor (Lloyd), with rear wheels lifted off ground.*

Fig. 20. *40 h.p. Thornycroft type Indian Lorry, with 2-wheeled Trailer.*

Figs. 22 and 23. *Types of Caterpillar Tractors.*

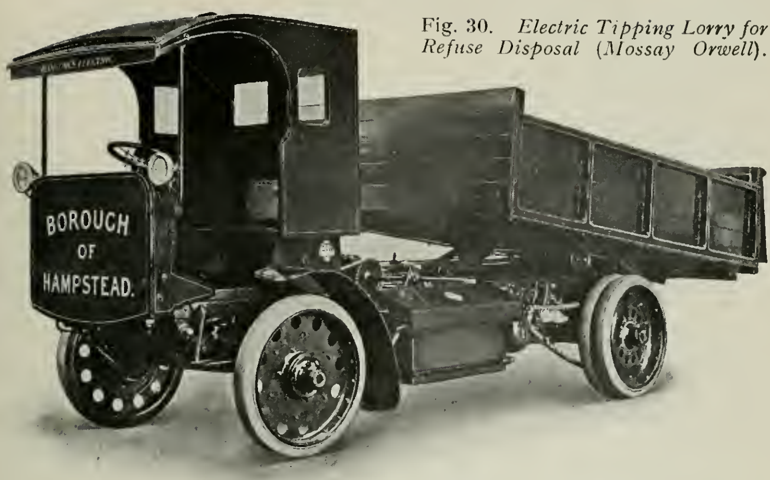


Fig. 30. *Electric Tipping Lorry for Refuse Disposal (Mossay Orwell).*

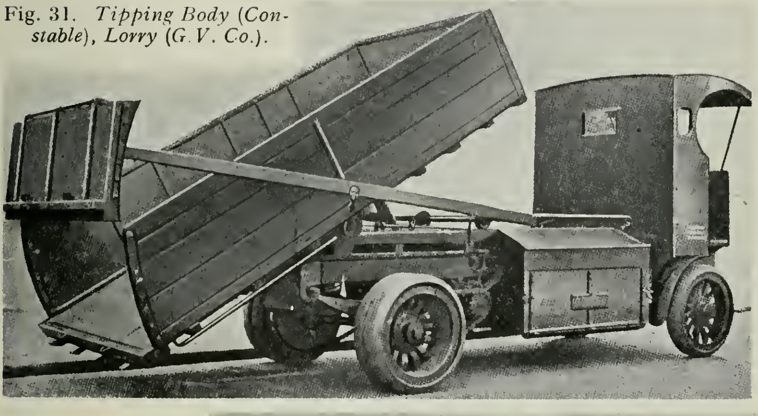


Fig. 31. *Tipping Body (Constable), Lorry (G.V. Co.).*

Fig. 37. *"Yorkshire" 6-ton Steam Lorry, with 2-ton power operated Crane.*

Fig. 38. *Electric Lorry (G. V. Co.) with Wilkin's Unloading Gear.*

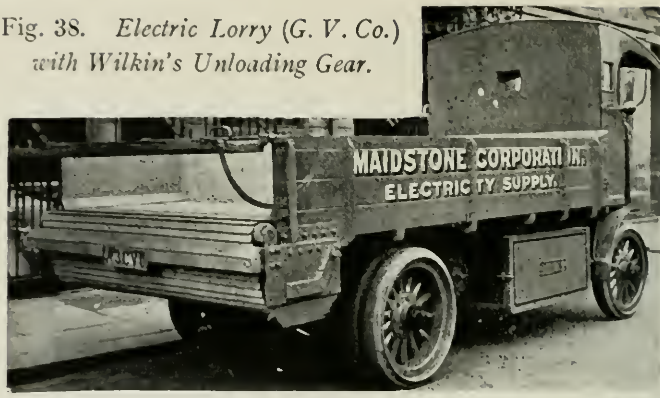


Fig. 39. *5-ton Steam Wagon (Clayton) with Wilkin's Gear.*

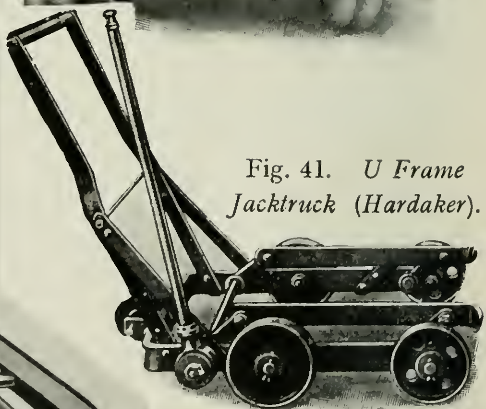


Fig. 41. *U Frame Jacktruck (Hardaker).*

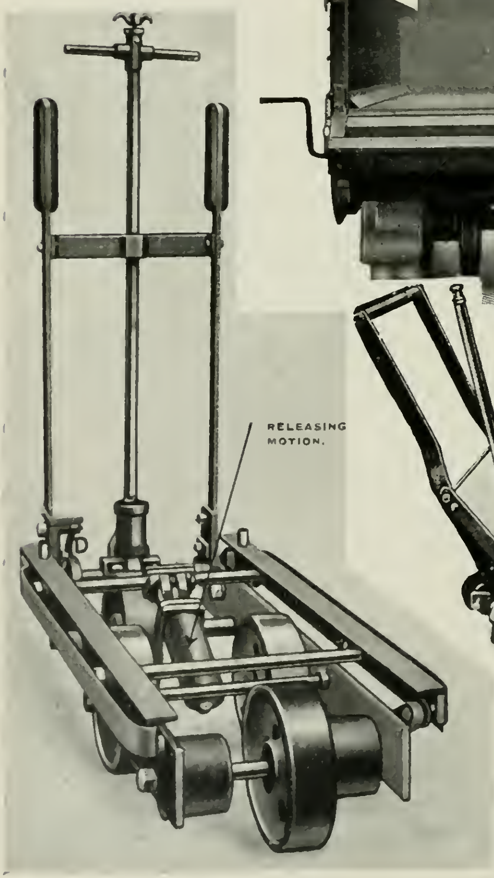


Fig. 40. *15-cwt. Jacktruck (Hardaker).*

(*Edison Accumulator Co.*).

Fig. 42. *Automatic Freight Truck.*

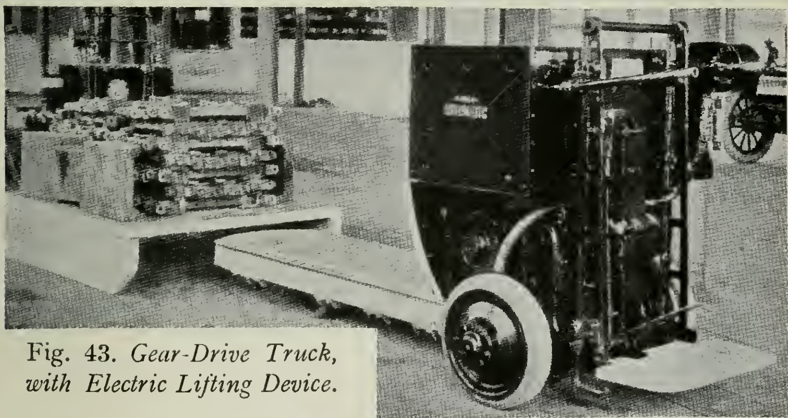
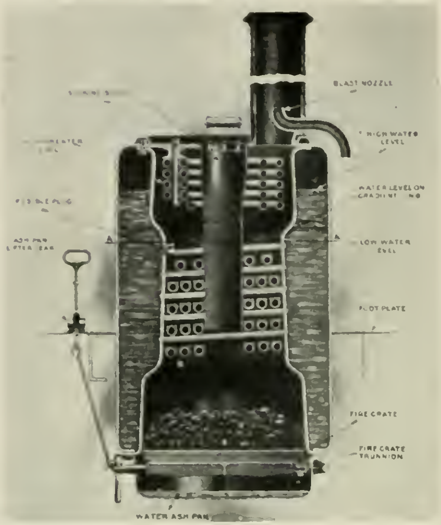


Fig. 43. *Gear-Drive Truck, with Electric Lifting Device.*

Fig. 44. *Automatic Truck, with Crane attached.*

MECHANICAL ROAD TRACTION.

Figs. 46 and 47. *Water-tube Boiler (Sentinel). Section and open for Inspection.*



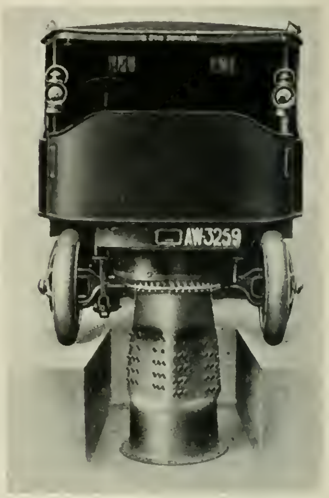


Fig. 48. *14-20 h.p. Steam-tractor (Foster).*

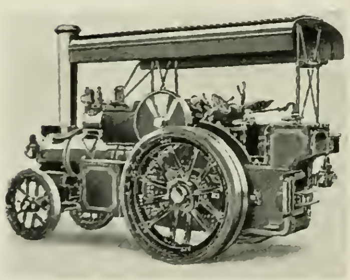


Fig. 49. *105 h.p. Petrol-tractor (Foster).*

Figs. 51, 52, and 53. *Bradford Vehicle, running on Battery, Trackless Trolley Route, and Earthing Shoe (Cross).*